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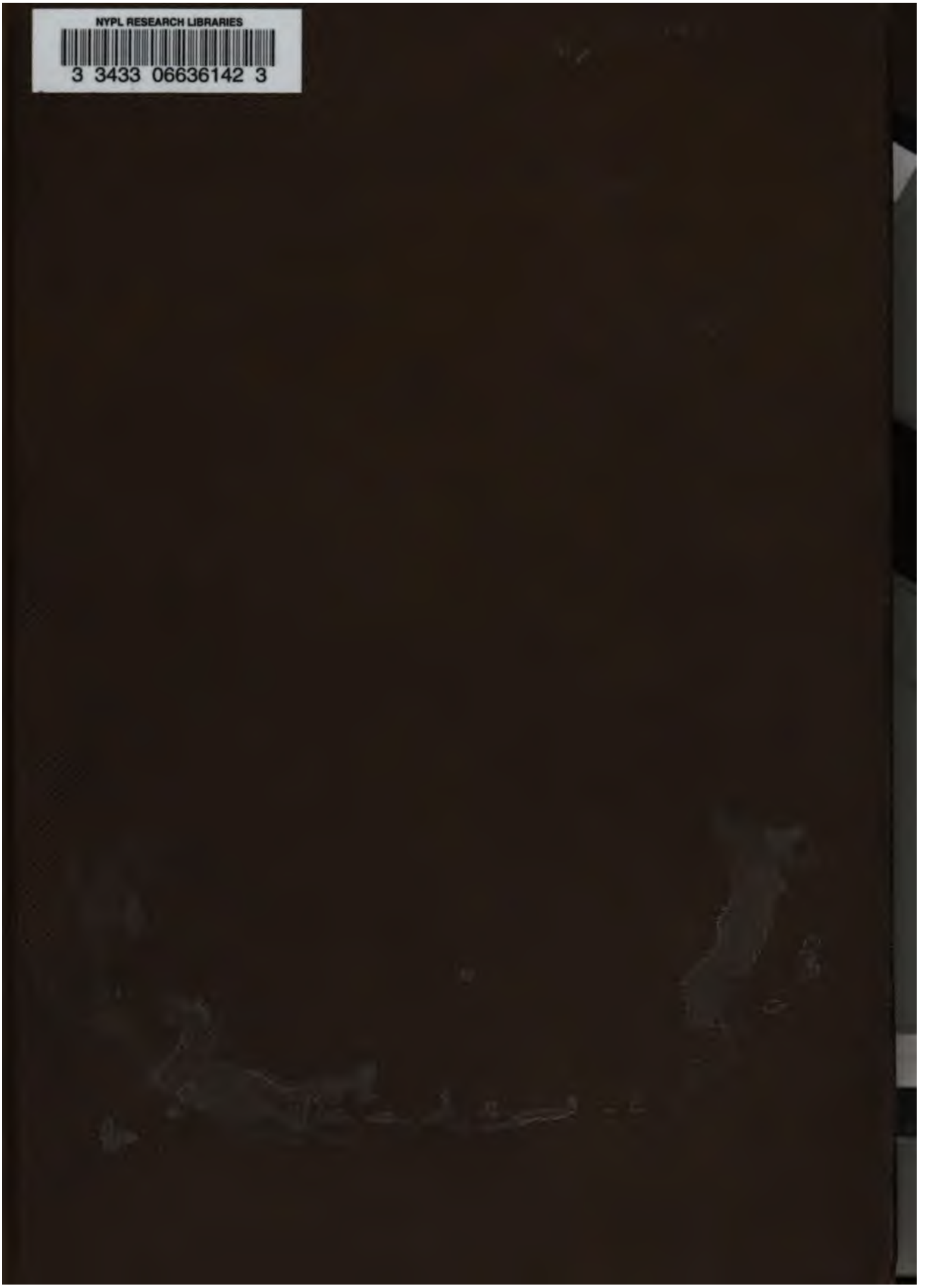

THE

TECHNOLOGY QUARTERLY

AND

PROCEEDINGS OF THE SOCIETY OF ARTS.

VOLUME XIV.

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THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY held its first meeting on April 8, 1862. By the act of incorporation, which was accepted at this meeting, the SOCIETY OF ARTS was created as a part of the Institute coördinate with the School of Industrial Science.

The objects of the Society are to awaken and maintain an active interest in the sciences and their practical applications, and to aid generally in their advancement in connection with the arts, agriculture, manufactures, and commerce. Regular meetings are held semi-monthly from October to May.

The Society discontinued the publication of the *Abstracts of Proceedings* in 1891, and since then has published its proceedings and the principal papers read at its meetings in the *Technology Quarterly*. The present volume contains the proceedings from October, 1900, to May, 1901, inclusive.

The *Quarterly* contains, also, the results of scientific investigations carried on at the Institute, and other papers of interest to its graduates and friends.

Neither the Massachusetts Institute of Technology nor the SOCIETY OF ARTS assumes any responsibility for the opinions or statements in the papers.

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Society of Arts.

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Editor of the Technology Quarterly.

ROBERT P. BIGELOW.

BY-LAWS.

Objects of the Society.

The objects of the Society are to awaken and maintain an active interest in the practical sciences, and to aid generally in their advancement and development in connection with arts, agriculture, manufactures, and commerce.

The Society invites all who have any valuable knowledge of this kind which they are willing to contribute to attend its meetings and become members. Persons having valuable inventions or discoveries which they wish to explain will find a suitable occasion in the Society meetings, subject to regulations hereafter provided; and while the Society will never indorse, by vote or diploma or other official recognition, any invention, discovery, theory, or machine, it will give every facility to those who wish to discuss the principles and intentions of their own machines or inventions, and will endeavor at its meetings, or through properly constituted committees, to show how far any communications made to it are likely to prove of real service to the community.

Section I. — Administration.

The immediate management and control of the affairs of the Society of Arts shall be exercised by an Executive Committee, consisting of the President of the Institute and the Secretary of the Society (who shall be members *ex officiis*), and five other members, who shall be elected by the Society of Arts at each annual meeting, to continue in office until other persons have been chosen in their place.

Sect. II. — Duties of the Executive Committee.

The Executive Committee shall elect its chairman, prescribe his duties, and, with the concurrence of the Treasurer of the Institute, fix his compensation when the interests of the Society require that

he should be paid for his services; they may invite any person to preside at any ordinary meeting who is well versed in the subjects to be discussed; they shall appoint the days and times of meeting, when not fixed by the Society, and determine the subjects to be considered at the meetings and the mode of conducting the discussions; they may, with the concurrence of the President of the Institute, make such arrangements for reporting and publishing the proceedings of the Society as they may deem best suited to advance its interests; they may receive moneys in behalf of the Society in aid of its objects, by subscription, donation, or bequest; they shall make a report of their doings to the Society at its annual meeting and at such other times as a report may be called for by a majority of the members present at any meeting; they shall also make a report of their doings to the President of the Institute prior to the annual meeting, and at such other times as the Corporation may require it. Three members shall constitute a quorum for the transaction of business.

Sect. III. — Duties of the President and Secretary.

1. It shall be the duty of the President of the Institute to preside at the annual and the special meetings of the Society, and also at its ordinary meetings when the Executive Committee does not invite a special chairman to preside.

2. It shall be the duty of the Secretary of the Society to give notice of and attend all meetings of the Society and of the Executive Committee; to keep a record of the business and orders of each meeting, and read the same at the next meeting; to keep a list of the members of the Society, and notify them of their election and of their appointment on committees; and generally to devote his best efforts, under the direction of the Executive Committee, to forwarding the business and advancing the interests of the Society. He shall also record the names of the Executive Committee attending each meeting.

Sect. IV. — Funds of the Society.

All the fees and assessments of members, and all moneys received by subscription, donation, or otherwise, in aid of the Society, shall be paid into the treasury of the Corporation, to be held and used for the objects of the Society under the direction of the Executive Commit-

tee, and shall be subject to the order of its Chairman, countersigned by the President of the Corporation.

Sect. V. — Meetings of the Society.

1. The annual meeting of the Society shall be held at the Institute on the second Thursday in May. The ordinary meetings shall be held semi-monthly, or whenever deemed expedient by the Society or by the Executive Committee, excepting in the months of June, July, August, and September.

2. If from any cause the annual meeting shall not have been duly notified or held as above required, the same shall be notified and held at such time as the Executive Committee may direct.

3. A special meeting of the Society may at any time be called by the Secretary on a written request of ten members. Twelve members of the Society shall constitute a quorum for the transaction of business.

Sect. VI. — Members and Their Election.

1. Members of the Society of Arts shall be of three kinds — Associate, Corresponding, and Honorary Members.

2. Candidates for Associate Membership shall be recommended by not less than two members, whose signatures shall be affixed to a written or printed form to that effect. Each nomination shall be referred to the Executive Committee, and when reported favorably upon by them, and read by the Secretary, may be acted upon at the same meeting; the election shall be conducted by ballot, and affirmative votes to the number of three fourths of the votes cast shall be necessary for an election.

3. Corresponding and Honorary Members may be elected in the same way, on nomination by the Executive Committee.

4. Associate Members shall pay an admission fee of three dollars before being entitled to the privileges of membership, and an annual assessment of three dollars on the first of October of each year, this sum to include subscription to the *Technology Quarterly and Proceedings of the Society of Arts.*

An Associate Member who shall have paid at any one time the sum of fifty dollars, or annual assessments for twenty years, shall become a member for life, and be thereafter exempted from annual assessments.

A member neglecting to pay his annual assessment for six months after being notified that the same is due shall be regarded as having withdrawn his membership, unless otherwise decided by the Executive Committee, which shall be authorized, for cause shown, to remit the assessments for any one year; and which shall moreover be empowered to exempt particular members from assessments whenever their claims and the interests of the Society make it proper to do so.

Sect. VII. — Election of the Executive Committee and of the Secretary.

1. At an ordinary meeting of the Society, preceding the annual meeting, a nominating committee of *five* shall be chosen, whose duty it shall be to nominate candidates for the Executive Committee, to post a list of the names selected in the office of the Secretary, and to furnish printed copies thereof to the members at or before the time of election.

2. At a meeting at which an election is to take place the presiding officer shall appoint a committee to collect and count the votes and report the names and the number of votes for each candidate, whereupon he shall announce the same to the meeting.

3. A majority of the votes cast shall be necessary to an election.

4. In the first organization under these By-Laws, the Executive Committee may be elected at an ordinary or special meeting.

5. Vacancies in the committee occurring during the year may be filled by the Society at an ordinary meeting.

6. The Secretary shall be elected by the Society, on nomination by the Executive Committee, at each annual meeting of the Society, or, in case of a vacancy during the session, at such other time as the Executive Committee may appoint; and he shall be reëligible in the same way at the pleasure of the Society.

7. The compensation of the Secretary shall be fixed from year to year by the Executive Committee with the concurrence of the Treasurer of the Institute.

Sect. VIII. — Committees of Arts.

1. The Members of the Society of Arts may be enrolled in divisions, under the following heads, according to the taste or preference of

the individual; each division to constitute a committee upon the subjects to which it appertains:

(1) On Mineral Materials, Mining, and the Manufacture of Iron, Copper, and other Metals.

(2) On Organic Materials — their culture and preparation.

(3) On Tools and Implements.

(4) On Machinery and Motive Powers.

(5) On Textile Manufactures.

(6) On Manufactures of Wood, Leather, Paper, India Rubber, and Gutta Percha.

(7) On Pottery, Glass, Jewelry, and works in the Precious Metals.

(8) On Chemical Products and Processes.

(9) On Household Economy; including Warming, Illumination, Water-Supply, Drainage, Ventilation, and the Preparation and Preservation of Food.

(10) On Engineering, Architecture, and Ship-building.

(11) On Commerce, Marine Navigation, and Inland Transportation.

(12) On Agriculture and Rural Affairs.

(13) On the Graphic and Fine Arts.

(14) On Ordnance, Firearms, and Military Equipments.

(15) On Physical Apparatus.

2. Any member may belong to more than one of the above-named Committees of Arts, but shall not at the same time be eligible as chairman in more than one.

3. It shall be competent for each Committee of Arts, of ten or more members entitled to vote, to organize; to elect annually in October, or whenever a vacancy shall occur, a chairman; to appoint its own meetings; and to frame its own By-Laws, provided the same do not conflict with the regulations of the Society of Arts.

Sect. IX. — Amendment and Repeal.

1. These By-Laws may be amended or repealed, or other provisions added, by a vote of three fourths of the members present at any regular meeting of the Society; provided that such changes shall have been recommended and approved in accordance with the By-Laws of the Corporation (see extract from By-Laws of Corporation as

printed below) and presented in writing at a preceding meeting of the Society.

2. These By-Laws shall take effect immediately after their approval by the Corporation and adoption by the Society, and all previous By-Laws are hereby repealed.

As amended December 9, 1897.

EXTRACT FROM THE BY-LAWS OF THE CORPORATION.

SECT. VI. — There shall be a Committee on the Society of Arts consisting of five members, appointed at the annual meeting of the Corporation, to hold office for one year, who shall have the general charge and supervision of the organization and proceedings of the Society, subject to the approval of the Corporation. It shall be their duty, in connection with a committee chosen by the Society, to frame By-Laws for the government of the Society, which shall take effect when adopted by the Society and approved by the Corporation.

February, 1894.

LIST OF MEMBERS.

DECEMBER, 1901.

Members are requested to inform the Secretary of any change of address.

LIFE MEMBERS.

Addicks, J. Edward . . . 903 Harrison Building, Philadelphia, Pa.
Atkinson, Edward . . . . . 31 Milk Street, Boston, Mass.

Beal, James H. . . . . 104 Beacon Street, Boston, Mass.
Bowditch, William I. . . . . 28 State Street, Boston, Mass.
Breed, Francis W. . . . . Lynn, Mass.

Dalton, Charles H. . . . . 20 Beacon Street, Boston, Mass.

Eastman, Ambrose . . . . . 53 State Street, Boston, Mass.
Endicott, William . . . . . 32 Beacon Street, Boston, Mass.

Foster, John . . . . . 25 Marlborough Street, Boston, Mass.

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PROCEEDINGS OF THE SOCIETY OF ARTS.

THIRTY-NINTH YEAR, 1900–1901.

BOSTON, October 11, 1900.

THE 542d regular meeting of the SOCIETY OF ARTS was held on this day at 8 P.M., in Room 22, Walker Building, Mr. George W. Blodgett presiding. Two hundred and seventy-five persons were present. The records of the Annual Meeting for the year 1899–1900 were read and approved. Messrs. C. B. Beasom and Franklin H. Davis, graduates of the Institute, were elected to Associate Membership. There being no further business, the Chairman introduced Mr. Louis Derr, Instructor in Physics at the Institute, who addressed the Society on "Color Photography"

The speaker referred to the well-known differences in the colors produced by the mixture of pigments and by the mixture of colored light. In the latter case the three primary sensations, or colors, are red, green, and violet, and by their proper combination the sensation of white or any known color may be produced. This forms the underlying principle of the Ives process for the reproduction of natural color effects. A lantern is provided with three sets of lenses, which transmit light respectively through three colored glasses, red, green, and blue-violet. By a suitable mechanical device the three col-

ored images overlap on the screen, and give a white image. Three negatives of an object are made through red, green, and blue-violet glasses respectively, and their corresponding positives formed. The positive obtained by the use of red glass is placed in front of the lens system which gives red light, and correspondingly for the other two positions. Reflection will show that on the screen the original object should appear in the natural colors. Many beautiful slides were shown. The objections to the process are the mechanical difficulties in securing the correct color toning, and the cost and labor of obtaining satisfactory positives. The Ives Kromoskope was also explained.

The second process described was one suggested by Professor Joly, of Dublin. It depends upon the theory of color mixtures, and the fact that the eye is unable to differentiate objects whose visual angle is less than 1 minute of arc. A plate of glass is ruled in succession with red, green, and blue-violet lines to the number of 80 each to the inch. An object is photographed through such a plate, the positive formed, and the latter is viewed through the original test plate, using white light as the source of illumination. The Joly process is essentially the Ives process reduced to the formation of the three-colored positives on one plate.

McDonough, of Chicago, has succeeded in ruling plates with 100 sets of lines to the inch, thus securing a more perfect color reproduction of the small details of an object. Certainly the Joly-McDonough process gives most satisfactory and true reproduction in color, if the slides which were shown are to serve as a criterion.

The last view which was shown, was one taken by the Lippmann process. This process is most interesting, since it is based on the interference of light, and gives a "true color photograph." By none of the processes is direct color printing possible. They merely offer a means of securing transparent positives in color.

The thanks of the Society were extended to Mr. Derr for his most entertaining and instructive lecture.

BOSTON, October 25, 1900.

The 543d regular meeting of the SOCIETY OF ARTS was held on this day at 8 P.M., in the Rogers Building, Mr. Desmond FitzGerald presiding. Seventy-two persons were present. The records of the

previous meeting were read and approved. The following were elected to Associate Membership: Dr. William H. Walker, Chemist; Mr. E. M. Fisher, of the Associated Press; Mr. H. P. Quick, with the Boston Elevated Railroad.

At the conclusion of the business portion of the meeting, Professor Wallace C. Sabine, of Harvard University, was introduced, and addressed the Society on "Some Experiments in Architectural Acoustics," limiting his remarks to those experiments which may be classified under the head of "Reverberation." A synopsis of the lecture will not be given as Professor Sabine has kindly presented his monograph on Reverberation to the Society.

As a piece of original research of unusual merit and value, the investigations on Architectural Acoustics, carried on by Professor Sabine during the last five years, are deserving of the highest commendation. For those present it was most interesting and instructive to learn of the earlier experiments, and to see how they led to more extensive and far-reaching investigations, ultimately resulting in a satisfactory and complete solution of the problem.

The thanks of the Society were most heartily extended to Professor Sabine for his valuable address.

BOSTON, November 8, 1900.

The 544th regular meeting of the SOCIETY OF ARTS was held on this day at the usual hour in the Walker Building. One hundred and thirty-five persons were present.

The following gentlemen were elected to Associate Membership: Mr. Olof Ohlson, Assistant Superintendent of Waltham Watch Factory; Mr. S. W. Wilder, Jr., Manager of the Merrimac Chemical Company; Mr. Edgar M. Hawkins, Mechanical Engineer, and Mr. J. E. Woodwell, Inspector of Electric Lights, Treasury Department, Washington.

There being no further business, the Society was privileged to listen to a most interesting lecture by Dr. Henry S. Pritchett, President of the Institute of Technology and of the Society, on "America's Contribution to our Knowledge of the Size and Figure of the Earth." The lecture had particular reference to the magnificent work which has been

done by the United States Coast and Geodetic Survey on the measurement of an arc of the 39th parallel, extending from Cape May Lighthouse to Punta Arenas in California, a distance of 4,224 kilometers. These measurements were begun in 1871, at the suggestion of Professor Benjamin Peirce, and completed in 1898, during the administration of Dr. Pritchett as Superintendent of the Coast and Geodetic Survey.

The main discussion of the figure of the earth rests upon the measurements of three arcs of meridian; one in Peru, one in Finland, and a third near the Cape of Good Hope. The Peruvian arc, determined in 1735, has remained as a standard in all geodetic work. Owing to the demand for its accurate remeasurement, the French Government has arranged to send an expedition in the Spring, which will remeasure the old arc and extend its length.

The 39th parallel was chosen by the United States Government as forming the longest line running east and west in the United States. The methods used in the base-line measurements,[1] as well as the procedure of triangulation were carefully described. Reference was also made to the improvements which had been made in instruments for measuring latitude, longitude, and altitude with the requirements of the survey. It should not be forgotten that the measurements were made over mountain ranges, in most inaccessible regions, at great risk to life, and testify to the courage and perseverance of the men engaged in the undertaking. Their reward lies in the knowledge that this arc is the longest ever measured with accuracy on the earth's surface, and gives to the earth the same figure as that determined from smaller arcs measured in Europe and Asia; agreeing with the spheroid as calculated by Captain Clark in 1880.

Besides the determination of the earth's figure, this arc of the 39th parallel is most valuable as a connecting link between the surveys of the Atlantic and Pacific Coasts, and, since it passes through sixteen states, serves as a sort of primary reference survey for all these states.

The thanks of the Society were tendered to Dr. Pritchett by Professor Swain on behalf of the Society.

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[1] An article on An Improvement in the Base-Line Measuring Apparatus, by Professor A. E. Burton, with a description of a successful test of it by the United States Coast and Geodetic Survey, is in the hands of the Editor and will appear in the next issue of this journal.

BOSTON, November 22, 1900.

The 545th regular meeting of the SOCIETY OF ARTS was held on this day in the Rogers Building, at 8 P.M., Mr. George W. Blodgett presiding. Seventy-five persons were present. Messrs. Howard D. Coburn and Arthur G. Woodman were elected to Associate Membership.

At the conclusion of the business part of the meeting, the speaker of the evening, Professor W. W. Crosby, Principal of the Lowell Textile School, was introduced and spoke on "Applied Science in the Textile World." After a most interesting statement of the need and advantage of science as applied to industries of all kinds, the speaker referred to the primitive methods used in the earlier textile industries, and compared them with the modern methods. The wonderfully ingenious machines for spinning and weaving, among them the card, mule, ordinary and Jacquard looms were explained.

A short reference was made to the aim of the Lowell Textile School, and many slides were shown illustrative of the splendid equipment which the school possesses.

The thanks of the Society were tendered the speaker, after which the meeting adjourned.

BOSTON, December 13, 1900.

The 546th regular meeting of the SOCIETY OF ARTS was held on this day at the Institute, Rogers Building, at 8 P.M., Mr. James P. Munroe presiding. One hundred and fifteen persons were present. After the reading and adoption of the report of the previous meeting, Mr. Guy Lowell, Architect, addressed the Society on "Landscape Architecture in this Country."

The history of landscape architecture dates back many years before the Christian era; indeed, descriptions of Egyptian gardens as far back as 1500 B.C. are mentioned in hieroglyphics. The art of gardening continued during the Roman Empire, but gradually died out. During the Renaissance, an awakening took place which has grown in its influence, especially since the beginning of the Seventeenth Century, when the Italian gardens became so famous. These gardens were laid out with geometrical regularity, adorned with statuary, native plants and trees. The terraces were their chief characteristics.

The French gardens were similar to the Italian gardens in the formality of lines and geometrical curves. During the reign of Louis XIV, some of the most famous gardens of France were constructed. These were usually free from terraces, but remarkable for long vistas, and profusion of arches, fountains, and grottoes.

With the spread of gardens through Europe, the "Formal" style of the ancients gradually yielded to conditions of climate and vegetation. In England, Kent abandoned the steep terraces and straight lines, substituting flowing lines, slopes, pleasing curves, irregularity in the arrangement of trees and shrubs.

The speaker emphasized that specific rules cannot be laid down in landscape architecture; the climate, character of land, and architecture must dominate the style. In this country the "Formal" gardens will doubtless be supplanted by gardens in which the wonderful richness and beauty of nature will be seen in all its glory. Untrimmed trees and flowering shrubs will be the principal features.

The thanks of the Society were extended to the speaker.

GEORGE V. WENDELL, *Secretary.*

THE ECLIPSE EXPEDITION OF THE CREIGHTON UNIVERSITY TO WASHINGTON, GEORGIA.

By WILLIAM F. RIGGE, S.J.

Creighton University has contributed its share towards the scientific observation of the total solar eclipse of May 28, 1900, so far as its means and circumstances permitted. As this great event occurred toward the end of the college year when its professors were unusually occupied with class duties and examinations, the Professor of Astronomy, the writer of the present account, was the only one who could be devoted to the work. Having invited the Professors of Astronomy of sister colleges to participate in the noble cause, Rev. Charles Charroppin, S.J., and Professor Aloysius Frumveller, S.J., of St. Louis University, St. Louis, Missouri, and Professor William P. Quinlan, S.J., of St. Xavier College, Cincinnati, Ohio, recognizing Creighton's initiative and its judicious selection of the site, freely offered a hearty coöperation. Washington, Georgia, was chosen as the place of observation, and the elegant little pastoral cottage attached to the St. Joseph's Academy and Orphanage, the occupant of which had just died in a hospital in Baltimore, was placed at our entire disposal, and every facility was offered for our work.

The observatory of Creighton University, at Omaha, Nebraska, while surpassed but by few students' observatories in the country, is not equipped with special eclipse instruments. Its 5-inch Steward equatorial, its 3-inch Fauth transit and meridian circle reading to tenths of a second, with its chronograph and its Howard mean time and Fauth sidereal clocks, are not portable, and as time and means were limited, their transportation and remounting were out of the question. The writer therefore had to content himself with an excellent chronometer and a 3-inch telescope with a tripod and an ordinary altazimuth mounting. But with this comparatively meager instrumental outfit, he was determined to do his best. To do work of real service to astronomical science, he further restricted himself exclusively to the observation of the four contacts. Then, as a professor of astronomy, he devoted the

rest of his energy to the visual observation of the corona and other phenomena of the eclipse. The other members of the party had mounted six cameras upon one support, and were intent upon the photographic reproduction of the corona.

Station.

Upon the grounds of the St. Joseph's Orphanage and Academy at the western end of Washington, Georgia, there are four main buildings connected by a private walk. Of these the Orphanage is at the northern end, the little cottage which served as our headquarters is next, then comes the Catholic church, and lastly the Academy at the southern end. While the rest of my party had erected their cameras in front, or east of the cottage, I took up my station on the walk halfway between the church and the residence, where, as I had planned, I was absolutely alone and entirely unbiased by the doings of others. Afterwards, when I realized that my observations were better than I had anticipated, I engaged Mr. Wiley G. Tatom, the Surveyor of Wilkes County, to connect my station with that of the Massachusetts Institute of Technology at the southern end of the town. Under date of June 22, 1900, he sent me the following field notes:

	Bearings.	Distances. Chains.
1	S. 66° E.	5.00
2	S. 86½° E.	43.60
3	S. 5° W.	28.00
4	S. 60° E.	7.30

The departures and differences of latitude are as follows, the distances being expressed in feet:

	Bearings.	Distances	N.	S.	E.	W.
1	S. 66° E.	330	....	134	302	....
2	S. 86½° E.	2,878	....	176	2,872	....
3	S. 5° W.	1,848	....	1,841	....	161
4	S. 60° E.	482	....	241	417	
				2,392	3,591	161
					161	
				2,392	3,430	

FIG. 1. — METHOD OF OBSERVATION.

According to the Smithsonian Geographical Tables, 1894, these distances are equivalent to $23.7''$ and $2.71s.$ respectively. Hence

	Latitude.			Longitude.		
Massachusetts Institute of Technology	33°	43′	49″	5*h.*	30*m.*	56.2*s.*
Reduction	+		23.″7	+		2 7*s.*
Creighton University	33°	44′	13″	5*h.*	30*m.*	58 9*s.*

The station of the Massachusetts Institute of Technology was therefore 4,180 feet S. 55° 7′ E. of that of the Creighton University.

The Method of Observation.

The internal contacts were observed with the naked eye. The external contacts were observed by projecting the sun's image upon a white screen secured by two light wooden rods beyond the eye-piece of the 3-inch telescope (see Figure 1). I prefer this way of observing the sun to the more usual direct-vision method by means of a sunshade or helioscope, because the projection method does away with the heat and glare of the sun, admits of the use of both eyes and of any desirable magnifying power, is equal, if not superior in accuracy of observation, and especially because it enables the observer to mark the point of first contact upon the screen and thus obtain the advantages of a position micrometer from a telescope of the most ordinary construction and mounting.

The Chronometer.

The chronometer was the box chronometer without its box, H. H. Heinrich, No. 502, beating half seconds. It kept central, or 90th meridian, time. The correction and rate were obtained from the 75th meridian noon signals at the railroad depot, which was at about a five minutes' walk from our cottage. As the signals were less than a tenth of a second in error, being $0.04s.$ late on May 26, and $0.02s.$ fast on May 28, their correction has been neglected. The chronometer corrections were as follows:

May 26, 1900	+	1*m.*	1.2*s.*
May 28, 1900	+	0	47.0

Hence the rate was $7.1s.$ a day gaining, or $0.3s.$ in one hour.

THE TIMES OF THE CONTACTS.

	I.	II.	III.	IV.
	h. *m.* *s.*	*h.* *m.* *s.*	*h.* *m.* *s.*	*h.* *m.* *s.*
Chronometer face	6 32 30	7 40 2	7 41 28	8 58 31
Correction at 11*h.* . . .	+ 47.0	+ 47.0	+ 47.0	+ 47.0
Rate to observed time . .	+ 1 3	+ 1.0	+ 1.0	+ 0.6
Central times	6 33 18 3	7 40 50 0	7 42 16.0	8 59 18 6

Comparison of Computed and Observed Times.

In preparation for the eclipse, the erroneous values of 33° 40′ 46″ for the latitude, and 5*h.* 30*m.* 49.5*s*, for the longitude, as measured from the government eclipse map, had been used. As soon as the true coordinates of my position became known to me, I recomputed the times of the phases and obtained the following results:

Central Time.	I.	II.	III.	IV.
	h. *m.* *s.*	*h.* *m.* *s.*	*h.* *m.* *s.*	*h.* *m.* *s.*
Computed	6 33 17 0	7 40 57.1	7 42 23 0	8 59 29 8
Observed	6 33 18.3	7 40 50.0	7 42 16.0	8 59 18 6
Computed — Observed . .	— 1.3	+ 7.1	+ 7.0	+ 11.2

Central Time.	Mid Totality.	Duration of Totality.	Duration of Whole Eclipse.
	h. *m.* *s.*	*m.* *s.*	*h.* *m.* *s.*
Computed	7 41 40.0	1 25.9	2 26 12.8
Observed	7 41 33 0	1 25 0	2 26 0.3
Computed — Observed . . .	+ 7.0	— 0.1	+ 12 5

Comparison of Times as Observed by Creighton University and Massachusetts Institute of Technology Parties.

A very interesting and useful part of the observations of the contacts in an eclipse is the comparison of the times as observed by different parties. It was only on November 23, 1900, that a reprint

from the *Technology Quarterly*, Vol. XIII, No. 3, September, 1900, containing the account of the "Eclipse Expedition of the Massachusetts Institute of Technology to Washington, Georgia," came into my hands. It had been kindly sent to me by Mr. G. L. Hosmer. As soon as I saw the observed times of the phases, I set to work at once to compare them with my own. For this purpose a reduction had to be computed which would make the observations at both stations comparable with one another. As this computation involved a considerable amount of labor, I thought a somewhat extended explanation of my method would be acceptable to the readers of this journal. I shall try to be brief without being obscure.

Reduction of the Times of the Exterior Contacts.

For the external contacts sufficient accuracy is secured by measuring the direction of the tangent to the moon's penumbra as given for every two-and-a-half minutes for the beginning, and every five minutes for the end of the eclipse, on the government map in the supplement to the *American Ephemeris*, 1900, and then supposing the direction of the penumbral motion to be at right angles to this tangent. The velocity was obtained by measuring the number of miles run in a minute, or the number of feet run in a second, on either side of Washington on the map. This gave the following results:

Penumbral front moved 3,942 feet a second from S. 14° W.
Penumbral rear moved 2,587 feet a second from S. 53° W.

Figure 2 represents the comparative location of the two observing stations and the direction of motion of the moon's penumbra at the external contacts. It will be seen that the first contact occurred 0.38*s*. sooner, and the fourth contact 0.50*s*. later, at the Massachusetts Institute of Technology station than at the Creighton University station. Hence the correction to the observed M. I. T. (Massachusetts Institute of Technology) times is + 0.4*s*. and — 0.5*s*. respectively, to reduce them to the C. U. (Creighton University) station.

Reduction of the Times of the Interior Contacts.

There are, in general, two kinds of solutions, according as the Fundamental Plane or the Washington Horizontal Plane is taken as the basis of computation.

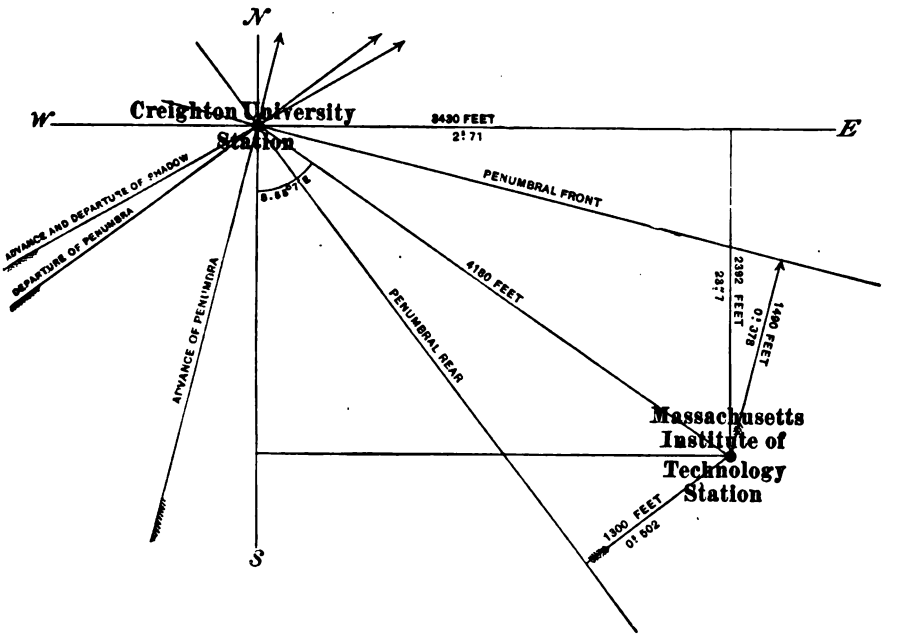

FIG. 2. — COMPARATIVE LOCATION OF THE ECLIPSE STATIONS.

I. The Fundamental Plane. — The Fundamental Plane is the plane, at right angles to the sun's rays, passing through Washington or the centre of the earth.[1] Figure 3 represents the shadow circle upon this plane with its radius equal to 0.00543 at the assumed instant of Greenwich time, $1^h.\ 41.6^m.$, or $7^h.\ 41^m.\ 36.0^s.$, A.M., Central time. O is the centre of this circle, C is the position of the Creighton University station, M that of the Massachusetts Institute of Technology, $G\ H$ and $P\ Q$ are the shadow chords which swept over the stations with F and K as their middle points. The little dot close to the centre of the shadow circle is the position of Washington as given on the eclipse map. The radii marked a, b, a', b', in parentheses, will be referred to afterwards. The numerical values of some of the quantities for both stations are as follows, the notation of the *American Ephemeris* being used throughout:

[1] This is not, strictly speaking, the Besselian Fundamental Plane used in the computation of eclipses, since the latter is normal to the line joining the centres of the sun and *moon* instead of the centres of the sun and *earth*, but as the angle between these two planes was only 6.6″ at mid-totality, the difference between them is too small to affect my present purpose.

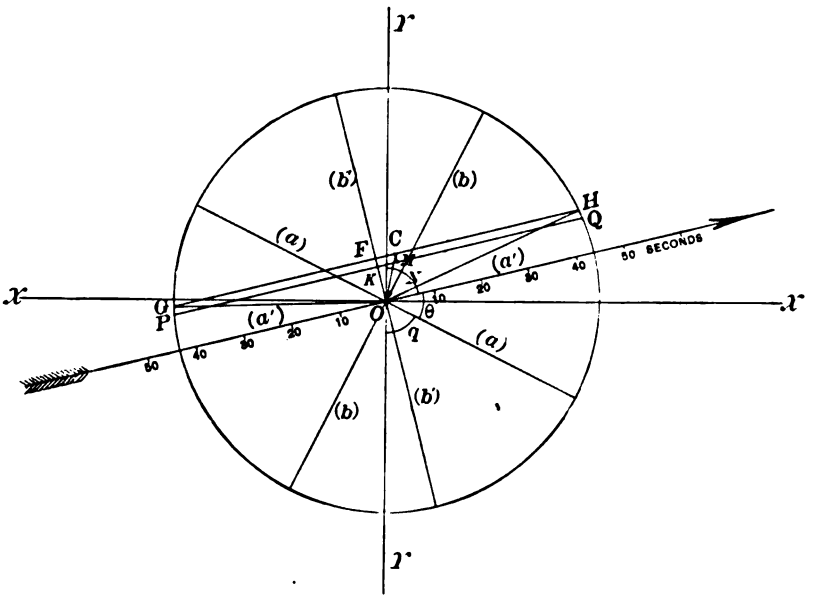

FIG. 3. — THE SHADOW CIRCLE UPON THE FUNDAMENTAL PLANE.

	Creighton University.	Massachusetts Institute of Technology.
$x - \xi$	— 0. 000 22	— 0. 000 23
$y - \eta$	— 0. 00 120	— 0. 00 107
M	190° 23′ 20″	192° 7′ 53″
N	76° 12′ 43″	76° 12′ 43″
$M - N$	114° 10′ 37″	115° 55′ 10″
m	0.00 12200	0 00 10944
n	0.00 74248	0.00 74248
ψ	11° 49′ 40″	10° 26′ 39″

The remaining quantities and the reductions will be given later on.

II. The Washington Horizontal Plane. — 1. Upon this plane the outline of the moon's shadow is an ellipse. The semi-minor axis, b, on Figure 4, is the same as the radius of the shadow circle on the Fundamental Plane (b), on Figure 3, and equal to 0.00543 in terms of the earth's equatorial radius as unity, or 21.560 miles. The semi-major axis $= a = b \sec \zeta = 34.245$ miles, ζ being the sun's zenith distance.

The local azimuth of this major axis is evidently that of the sun N. 88° 31′ 54″ E. The direction of motion, a, of the shadow ellipse

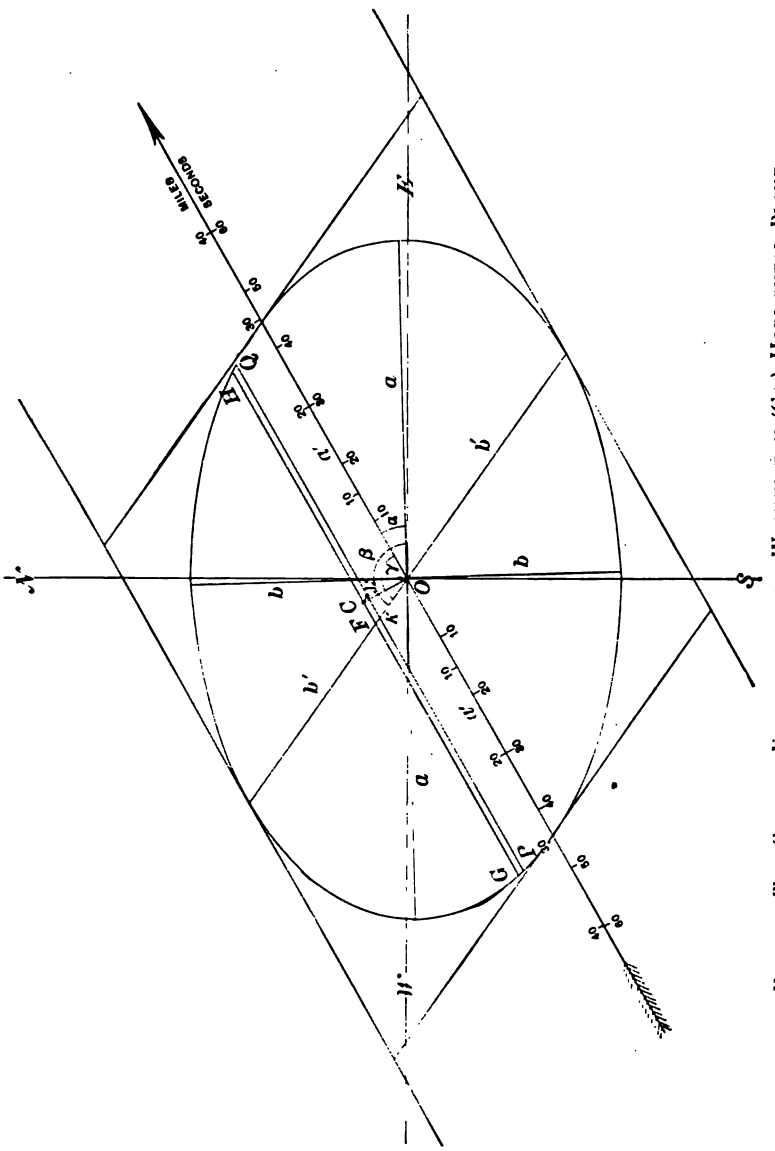

FIG. 4.—THE SHADOW ELLIPSE UPON THE WASHINGTON (GA.) HORIZONTAL PLANE.

with reference to the sun's azimuth, may be found from the formula

$$\tan a = \cos \zeta \tan \theta,$$

in which $\theta = 180° - (V + q) = 40° 25' 44''$ (see Figure 3) is the

angle between the direction of motion of the shadow on the Fundamental Plane with reference to the sun, N is the Ephemeris N, and q is the sun's local parallactic angle. This gives the azimuth of the shadow advance = S. 60° 19′ 24″ W.

The diameter of the ellipse, $2a'$, which lies in the direction of its motion upon the ground, has evidently for its conjugate the line of mid-totality, $2b'$. As these diameters of the ellipse are brought up from the Fundamental Plane where they are at right angles to one another (see Figure 3, where they are marked in parentheses), we find their constants to be

$$a' = b \sin \theta \operatorname{cosec} \alpha = 29.512 \text{ miles},$$
$$b = b \cos \theta \operatorname{cosec} \alpha' = 27.614 \text{ miles},$$

the angle between them $= \gamma = 115° 19' 37''$,
in inclination of a' to $a = \alpha =$ 28° 12′ 30″,
and of b' to $a = \beta = 143° 32' 7''$.

The velocity of the shadow, v, is $2a'$ divided by the duration of totality upon the central line, that is, $v = \frac{a'}{43.88s.} = 0.67413$ mile or 3,559 feet a second.

As all right lines parallel to a' and b' are projected from the Fundamental upon the Horizontal Plane in corresponding ratios, we find $OF = b' \sin \psi = 5.660$ miles. Then the bearing and distance of C, the Creighton University Station, from O, the centre of the shadow at the assumed moment, $1h.\ 41m.\ 36.0s.$, Greenwich time, together with the length and bearing of OF, determine the triangle FOC, from which we find $FC = 2.6563$ miles which are run by the shadow in $3.94s$. This, therefore, is the correction to the assumed time of mid-totality. $GF = a' \cos \psi = 28.952$ miles, and is run in $42.948s.$, thus giving the instants of the beginning and end of totality at the Creighton station.

In investigating the position of the Massachusetts Institute of Technology station, we find the line CM practically parallel to FO, the divergence being only 0° 6′ 25″, showing that the moments of mid-totality were identical at both stations. The distance of M from C being subtracted from FO and yielding KO, the equation of the ellipse gives us $PK = 29.117$ miles run in $43.193s$. The further results will be seen later.

In this method, as well as in all the others, the dimensions, velocity and direction of the shadow ellipse may be assumed to remain constant for one minute without introducing any sensible error into the computation.

2. Another method of examining the instantaneous constants of the shadow ellipse is to determine the lengths and inclinations of the conjugate diameters from the formulæ

$$\tan \alpha \tan \beta = -\frac{b^2}{a^2},$$
$$a'^2 + b'^2 = a^2 + b^2,$$
$$a'\, b' \sin \gamma = ab.$$

These give

$$a' = 29.62 \text{ miles},$$
$$b' = 27.58 \text{ miles},$$
$$\alpha = 28^\circ\ 12'\ 30'',$$
$$\beta = 143^\circ\ 32'\ 7'',$$
$$\gamma = 115^\circ\ 19'\ 37'',$$
$$v = 0.67504 \text{ mile, or } 3{,}564 \text{ feet a second,}$$

in which the angles are the same as in the previous method, but the lengths of the lines are slightly different.

From the known length of CO and the angles in the triangle FOC, we find $FC = 2.6758$ miles run in $3.964s.$, and $OF = 5.7015$ miles. The formula of the ellipse then gives $FG = 28.980$ miles run in $42.932s.$ Knowing the distance and bearing of M from C, we find the difference of the times of mid-totality to be $0.0024s.$ Then the usual equation of the ellipse gives $KP = 29.144$ miles run in $43.174s.$

3. A third method consists in measuring the necessary data from the government eclipse map. The distance between the mid-totality lines gives the velocity of the shadow equal to 42.2 miles per minute, or 3,712 feet per second, and its direction as from S 60° W. As the duration of totality on the central line was here $1m.\ 27.8s.$, the semi-major axis of the shadow ellipse was found to be $= a' = 30.25$ miles. By measurement parallel to the mid-totality lines, the conjugate semi-minor axis was found to be $= b' = 26.75$ miles, and the angle between the axes $= \gamma = 111^\circ\ 30'$. With these data, the formulæ

$$a'\, b' \sin \gamma = ab,$$
$$a'^2 + b'^2 = a^2 + b^2,$$
$$c = \sqrt{a^2 - b^2},$$
$$e = \frac{c}{a},$$
$$x' = \sqrt{\frac{a^2 - b'^2}{c^2}},$$
$$\cos \alpha = \frac{x'}{a'},$$

$$\beta = \gamma + a,$$

gave
$$a = 33.60 \text{ miles},$$
$$b = 22.42 \text{ miles},$$
$$a = 25^\circ\ 30',$$
$$\beta = 137^\circ\ 0'.$$

4. By using the sun's azimuth and the formula

$$\tan a = \cos \zeta \tan \theta,$$

we find
$$a = 28^\circ\ 23'\ 44'',$$
$$\beta = 143^\circ\ 19'\ 10'',$$
$$\gamma = 114^\circ\ 55'\ 26'',$$
$$a = 33.97 \text{ miles},$$
$$b = 21.56,$$
$$a' = 29.34,$$
$$b' = 27.53.$$

The further reduction of the results in these two last cases is by the same method as in the second solution. But as measurements on a map cannot compete in accuracy with computed values, no use has been made of these results except as checks upon the computation.

COMPARISON OF THE RESULTS OF THE METHODS OF REDUCTION.

	Creighton University.			Massachusetts Institute of Technology.		
	Fund. Plane.	Horizontal Plane.		Fund. Plane.	Horizontal Plane.	
		1.	2.		1.	2.
Assumed Central Time of Mid-totality. $7h.\ 41m.$	*s.* 36 00	*s.* 36 00	*s.* 36.00	*s.* 36.00	*s.* 36.00	*s.* 36.00
Time to run FC and $KM = + t_2$	4.04	3.94	3.96	3.87	3.94	3.96
Mid-totality. $7h.\ 41m.$	40 04	39.94	39 96	39.87	39.94	39.96
Time to run FG and $PK = \pm t_1$	42.95	42.95	42.93	43.15	43.19	43.17
Beginning of totality. $7h.\ 40m.$	57.09	56.99	57.03	56 72	56.75	56.79
End of totality. $7h.\ 42m.$	22.99	22.89	22.89	23.02	23.13	23.13
Reduction of M. I. T. to C. U. — Beginning,	....	....	....	+0 37	+0.24	+0 24
Reduction of M. I. T. to C. U. — End	....	....	....	−0.03	−0.24	−0.24
Duration of totality	85.90	85.90	85.86	86.30	86.38	86.34
Difference	....	....	....	−0.40	−0 48	−0.48

As the *American Ephemeris* gives its data only to five decimal places, differences of tenths of a second in the reduction can hardly be relied upon. However, giving the reductions computed upon the Fundamental Plane half the weight of either of those obtained from the Horizontal Plane, we find that we must add + 0.3*s*. and — 0.2*s*. to the observed times at the Massachusetts Institute of Technology station in order to reduce them to those observed at the Creighton University station, and hence for all four contacts the reductions are

I.	II.	III.	IV.
+0.4*s*.	+0.3*s*.	—0.2*s*.	—0.5*s*.

The Observations of the Contacts made by the Massachusetts Institute of Technology Reduced to the Creighton University Station.

The *Technology Quarterly* quoted above (September, 1900), on pages 171 and 172, gives the times of the contacts as observed by Mr. Hosmer and Professor Robbins. As these are expressed in Washington local mean time, we add to them the Greenwich longitude of the place, 5*h*. 30*m*. 56.2*s*., and then subtract 6*h*. 0*m*. 0*s*., in order to reduce them to Central time, and lastly add also the above-computed reductions in order to reduce them to the Creighton University station. The results are then as follows:

George L. Hosmer.	I.	II.	III.	IV.
	h. *m*. *s*.	*h*. *m*. *s*.	*h*. *m*. *s*.	*h*. *m*. *s*.
Washington time	7 2 22.7	8 9 52.0	8 11 18.2	9 23 26.9
Greenwich longitude	+5 30 56.2	+5 30 56.2	+5 30 56.2	+5 30 56.2
Red. to Central time	—6 0 0.0	—6 0 0.0	—6 0 0.0	—6 0 0.0
Red. to C. U. Station	+ 0.4	+ 0.3	— 0.2	— 0.5
Central time at C. U. Station	6 33 19.3	7 40 48.5	7 42 14.2	8 59 22.6

ARTHUR G. ROBBINS.	I.	II.	III.	IV.
Washington time	h. m. s. 7 2 16 4	h. m. s. 8 9 53.1	h. m. s. 8 11 18.4	h. m. s. 9 28 16.1
Greenwich longitude	+5 30 56.2	+5 30 56 2	+5 30 56 2	+5 30 56 2
Red. to Central time	−6 0 0.0	−6 0 0 0	−6 0 0.0	−6 0 0.0
Red. to C. U. Station	+ 0.4	+ 0 3	− 0.2	− 0.5
Central time at C. U. Station	6 33 13.0	7 40 49.6	7 42 14.4	8 59 11.8

GENERAL COMPARISON OF COMPUTED AND OBSERVED TIMES.

Central Times.	CONTACTS. I.	II.	III.	IV.	Mid-totality.	Duration of totality.	Duration of whole eclipse.
	h. m. s.	h. m. s.	h. m. s.	h. m. s.	h. m. s.	m. s.	h. m. s.
Computed	6 33 17.0	7 40 57.1	7 42 23.0	8 59 29.8	7 41 40.0	1 25.9	2 25 72.8
Observed by Rigge	18.3	50.0	16.0	18.6	33.0	1 26.0	60.3
Observed by Hosmer	19.3	48.5	14.2	22.6	31.4	1 25.7	63.3
Observed by Robbins	13.0	49.6	14 4	11.8	32.0	1 24.8	58.8
Computed Minus Observed — Rigge	−1.3	+7.1	+7.0	+11.2	+7.0	−0 1	+12.5
Computed Minus Observed — Hosmer,	−2 3	+8.6	+8.8	+ 7.2	+8.6	+0.2	+ 9.5
Computed Minus Observed — Robbins,	+4.0	+7.5	+8.6	+18.0	+8 0	+1.1	+14.0
Hosmer — Rigge	+1.0	−1.5	−1 8	+ 4.0	−1.6	−0.3	+ 3.0
Robbins — Rigge	−5.3	−0.4	−1.6	− 6 8	−1.0	−1.2	− 1.5
Hosmer — Robbins	+6.3	−1.1	−0.2	+10.8	−0.6	+0.9	+ 4.5

CREIGHTON UNIVERSITY,
Omaha, Neb., January 1, 1901.

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CHANGES THAT TAKE PLACE IN THE BACTERIAL CONTENTS OF WATERS DURING TRANSPORTATION.

By GEORGE C. WHIPPLE.

Bacteriologists are agreed that in order to obtain the most accurate determination of the number of bacteria in a sample of water the plating should be done at the time of collection. It was early observed that if this were delayed the resulting count would be different from that obtained by immediate plating. Unless the sample was kept on ice or in a cool place, the number of bacteria generally increased on standing, the increase in 24 hours being sometimes several hundred per cent. Even when kept on ice the number of bacteria did not remain constant, but sometimes increased, and occasionally decreased. In the vast majority of cases in actual practice immediate plating is an impossibility. A knowledge of the changes that take place in the bacterial contents of waters when kept for various lengths of time under different conditions is, therefore, a matter of great importance, and in view of its importance, the experimental evidence upon the subject is surprisingly meager.

Dr. E. O. Jordan[1] and Mr. E. E. Irons have pointed out that when samples of water are stored in ice, the number of bacteria sometimes decreases and sometimes increases during the first two days after collection, and that this can be explained, in part at least, by the initial temperature of the water. During the summer the change from the initial temperature of surface waters to the temperature of the ice box is ordinarily considerable, and the shock produced by the sudden cooling causes a reduction of vitality, or possibly death, to some of the bacteria present, while during the winter this change in temperature is less marked.

In general, the observations of the author tend to corroborate these statements, but experiments seem to show that many other

[1] E. O. Jordan and E. E. Irons. Notes on Bacterial Water Analysis. Reports of American Public Health Association, Vol. XXV, p. 564.

factors enter into the problem. For example, it has been found that whether the sample is stored in ice or at room temperature, the number of bacteria first diminishes and later increases. This is illustrated in the following table:

Sample.	Initial temperature.	Temperature of incubation of sample.	Number of Bacteria Per c.c.				
			Initial.	After 3 hours.	After 6 hours.	After 24 hours.	After 48 hours.
A . .	7.6° C.	17.0° C.	260	215	230	900	27,000
B . .	7.6°	17.0°	260	245	255	720	10,850
C . .	7.6°	12.5°	260	270	231	600	2,790
D . .	7.6°	12.5°	260	270	245	710	1 800
E . .	7.6°	2.4°	260	243	210	675	1,980
F . .	7.6°	2.4°	260	235	270	560	1,980
G . .	11.0°	12.8°	77	55	58	101	10 250
H . .	11.0°	12.8°	77	53	74	87	2.175
I . .	11.0°	23.6°	77	51	52	11,000	41,400
J . .	6.7°	20.0°	430	375	245	...	385,000[1]
K . .	6.7°	20.0°	430	345	405	....	750,000[1]
L . .	23.2°	23.0°	510	340	230	8,000	20,000
M . .	23.2°	2.5°	525	300	220	380	2,200

[1] 0.0005 per cent. peptone added to the water.

In order to determine whether this reduction was due to the death or to the reduced vitality of the bacteria present, whether to the aggregation of the bacteria, or to their attachment to the sides and bottom of the sample bottle, the following experiments were made. Fifty cubic centimeters of tap water were put into a 2-ounce chemical salt-mouth bottle, and allowed to stand in the 20° incubator for 3 hours. The water originally contained 99 bacteria per c.c., this figure being the average of 5 plates. At the end of 3 hours the bottle was thoroughly shaken and 2 plates made, the resulting counts being 84 and 87. The water was then poured out, the bottle drained, and 50 c.c. of sterile distilled water added. After shaking, 2 plates were

made as before, the counts being 1 and 2 respectively. The distilled water was then poured out, leaving behind only those bacteria that had become attached to the glass; 10 c.c. of standard nutrient gelatin were then put in the bottle and a roll-culture made. The number of colonies that developed was 84, or approximately 1.5 for each cubic centimeter of water. At the end of three hours, therefore, the sample contained $\frac{84+87}{2} + \frac{1+2}{2} = 87$ per c.c., or 12 per c.c. less than the original number. A second sample collected at the same time was kept 6 hours in the incubator, and treated in a similar manner. At the end of this period the water contained 56 bacteria per c.c., and 118 were obtained by the roll-culture, equal to more than 2 per c.c. of the original water. A second experiment of the same kind gave the following results:

	Sample A.	Sample B.	Sample C.	Sample D.
Number of bacteria at time of collection . . .	255	275	330	280
Number of bacteria after 5 hours	225	220	...	...
Number of bacteria after 24 hours	...	...	25,000	30,000
Number of bacteria in distilled water used for washing	1	1	230	270
Number of bacteria in bottle, by roll culture . .	365	296	37,000	30,000

These experiments indicate that the decrease in the number of bacteria immediately after collection cannot be explained by loss from precipitation upon the glass, but they also indicate that the error introduced by this cause may be important if the sample is allowed to stand for a considerable time.

There seemed to be a possibility that the decrease in number might be due to the aggregation of the bacteria upon standing with consequent reduction in the number of colonies. The following experiment apparently disproves this. Two samples of tap water were collected in 2-ounce bottles, and incubated for 3 hours at the initial temperature, 22° C. Bottle *A* was almost full; bottle *B* was about one-third full. From each of these bottles duplicate samples were withdrawn after giving ten gentle shakes, and again after shaking vigorously two hundred times.

Sample.	Number of Bacteria Per c.c.	
	Initial.	After 3 hours.
A. Shaken ten times	590	380
A. Shaken two hundred times	580	360
B. Shaken ten times	645	370
B. Shaken two hundred times	610	390

The decrease in the number of bacteria after collection in small bottles seems, therefore, to be due to the effect of changed environment upon the bacteria. It has been observed that when a sample is kept at its initial temperature, the change in the bacterial contents is less than when kept at a different temperature. It has been also noticed that this change was somewhat greater in samples taken from service taps where the bacteria had been under pressure, than in samples taken from the surface of a reservoir. Further, it is a matter of common observation that samples plated at the time of collection show a greater number of different species than the same samples plated 24 hours after collection.

The character of the bottle has an effect upon the rapidity of growth of bacteria. This fact was observed by the author several years ago, but its importance was not appreciated until the following experiments were made.

Tap water was collected in four bottles and incubated for 72 hours at 18°. The initial temperature of the water was 12.5° C. Sample *A* was collected in a 2-quart glass-stoppered sterilized bottle, and the bottle was completely filled, leaving no air space. Sample *B* was collected in a similar bottle which was but half filled. Sample *C* was taken in a 2-ounce chemical salt-mouth bottle completely filled, and sample *D* in a 2-ounce bottle half filled. Duplicate plates were made from each bottle at intervals with the following results:

Sample.	Number of Bacteria Per c.c.			
	Initial.	After 24 hours.	After 48 hours.	After 72 hours.
A. 2-quart bottle, completely filled . .	99	85	161	195
B. 2-quart bottle, half filled	99	90	570	705
C. 2-ounce bottle, completely filled . .	99	...	...	6,450
D. 2-ounce bottle, half filled	99	285	850	125,000

A second experiment made in the same way except that the water samples were incubated at 37° instead of at 18° C., gave the following results:

Sample.	Number of Bacteria Per c.c.	
	Initial.	After 24 hours.
A. 2-quart bottle, completely filled	160	1,900
B. 2-quart bottle, half filled	160	2,800
C. 2-ounce bottle, completely filled	160	68,000
D. 2-ounce bottle, half filled	160	72 000

In the third experiment bottles of various sizes were used, and the incubation was made at 13° and at 24° C., these being the averages of the observed temperatures. In order that the temperatures should be the same for each series, the bottles were kept in tanks filled with water, the necks of the bottles projecting above the water. In all cases the bottles were half full. The results are given in the following table.

Sample.	Bottle.	Temperature of incubation.	Number of Bacteria Per c.c.					
			Initial [1]	After 3 hours.	After 6 hours.	After 12 hours.	After 24 hours.	After 48 hours.
A.	1-gallon	13°	77	63	65	47	42	175
B.	2-quart	13°	77	59	63	60	45	690
C.	1-quart	13°	77	63	63	47	46	325
D.	1-pint	13°	77	57	61	36	38	630
E.	2-ounce	13°	77	55	58	47	101	10,250
F.	1-gallon	24°	77	81	97	275	290	300
G.	2-quart	24°	77	92	59	62	180	250
H.	1-quart	24°	77	84	77	46	340	900
I.	1 pint	24°	77	51	46	100	2.950	7,020
J.	2-ounce	24°	77	51	52	145	11,000	41,400

[1] Average of five plates.

A comparison was then made between the growth in 2-ounce bottles and in 250 c.c. flasks plugged with cotton, the samples being incubated at three different temperatures.

Sample.	Receptacle.	Temperature of incubation.	Number of Bacteria Per c.c.				
			Initial.[1]	After 3 hours.	After 6 hours.	After 24 hours.	After 96 hours.
A.	250 c.c. flask, filled to neck . . .	2.5°	260	235	270	560	1,980
B.	250 c.c. flask, half filled	2.5°	260	285	295	490	2,070
C.	2-ounce bottle, completely filled . .	2.5°	260	243	210	675	1,980
D.	2-ounce bottle, half filled	2.5°	260	275	255	595	12 600
E.	250 c.c. flask, filled to neck	12.5°	260	270	231	600	2,790
F.	250 c.c. flask, half filled	12.5°	260	295	280	705	1,890
G.	2-ounce bottle, completely filled . .	12.5°	260	270	245	710	1,800
H.	2-ounce bottle, half filled	12 5°	260	285	260	670	18,000
I.	250 c.c. flask filled to neck	17.0°	260	245	255	720	10,850
J.	250 c.c. flask, half filled	17.0°	260	255	290	1,510	....
K.	2-ounce bottle, completely filled . .	17.0°	260	215	230	900	27,000
L.	2-ounce bottle, half filled	17.0°	260	258	258	1,800	37,800

[1] Average of five plates.

Comparisons were next made in bottles of one size containing different amounts of water. The bottles had a capacity of 120 c.c. In this experiment 0.0005 per cent. of peptone was added to hasten the growth. The incubation was made at a temperature of 19.5° C. The following results were obtained:

Sample.	Amount of water in cubic centimeters.	Depth of water in centimeters.	Number of Bacteria Per c.c.	
			Initial.	After 36 hours.
A.	120[1]	15.0	430[2]	385,000
B.	100	12.5	430	510,000
C.	50	6.3	430	559,000
D.	20	2.5	430	656,000

[1] Bottle full.

[2] Average of five plates.

These experiments seem to justify the following conclusions: After the collection of a sample in either a large or a small bottle, there is a slight reduction in the number of colonies that can be obtained upon the gelatin plate, due apparently to the effect of changed environment upon the bacteria present. This reduction is perhaps somewhat greater when a small volume of water is collected, as its temperature change is naturally more rapid. The subsequent growth takes place more rapidly in a small bottle than in a large bottle, and more rapidly when the bottle is but partially filled than when it is completely full. With bottles of the same size the growth is more rapid in small volumes of water than in large volumes. The explanation of this is not wholly clear, but undoubtedly the supply of oxygen is an important factor, and it is probably the controlling factor.

These results have a practical bearing upon the procedure of the water analyst. They show first the great advantage of plating immediately after collection. They show that bottles larger than the customary 2-ounce salt-mouths should be used if the samples are to be kept long before plating, and that the bottles should be filled almost full. (It is necessary to leave a small amount of air space for expansion or contraction due to temperature changes.) But they also show that if the plating is made within a few hours of collection, the character of the bottle is practically immaterial, provided of course, that it is perfectly clean and sterilized.

During transportation, samples of water are usually subjected to more or less jolting, and the water is therefore kept in a state of agitation. In order to determine what effect gentle agitation has upon bacteria, the following experiment was made:

A 250 c.c. sterilized flask was partially filled with the sample and floated near the surface of water in a beaker. The water in the beaker was then kept in a state of commotion by blowing in air from a Richards pump. The rising bubbles caused the flask to bob about in a lively manner, keeping its contents continually in motion. The apparatus was placed in the incubator, the air tube being passed through one of the ventilating holes. A second flask that contained an equal amount of the sample was put in a second beaker and kept by the side of the first in order that temperature conditions might be the same. This flask was kept quiet. The incubator maintained an average temperature of 20°, and the atmosphere was saturated with

moisture. The initial temperature of the sample was 9.0° C. At intervals duplicate plate cultures were made from the two flasks. The following were the results:

Sample.	Number of Bacteria Per c.c.				
	Initial.	After 2 hours.	After 18 hours.	After 24 hours.	After 42 hours.
Quiet flask	225	193	365	445	1,690
Agitated flask . . .	212	186	340	385	1,120

A duplicate experiment gave similar figures. The temperature of the incubator was 23.5° C.

Sample.	Number of Bacteria Per c.c.		
	Initial.	After 5 hours.	After 48 hours.
Quiet flask	141	190	5,000
Agitated flask	141	146	3,100

The experiment was then modified by putting the samples into sterilized, wide-mouthed, 2-ounce bottles and blowing air into one of them. The air from a Richards pump was made to pass through a double cotton filter and through a sterilized rubber tube connected with a glass tube that entered the bottle. A T connection permitted a part of the air to be passed into a third bottle filled with sterilized distilled water, and run as a blank to determine whether the air carried any bacteria into the sample. The flow of air into the bottle that contained the sample was regulated so that about two bubbles per second rose in the water. The apparatus was placed in the incubator where the average temperature was 23.0° C. The following results were obtained:

Sample.	Number of Bacteria Per c.c.		
	Initial.	After 4 hours.	After 20 hours.
Quiet sample	240	235	1,250
Aerated sample	240	225	625
Aerated blank sample	0	...	2

In order to determine the effect of more violent shaking, a sample of water in a 2-ounce bottle packed in a tin box was attached to the piston rod of a pumping engine, while a duplicate sample was kept quiet near by. Both bottles were but partially filled. The engine was pumping at the rate of 60 strokes per minute, and the length of the stroke was about 2 feet. The temperature of the room varied from 21.0° to 26.0° C.

Sample.	Number of Bacteria Per c.c.	
	Initial.	After 18 hours.
Quiet bottle	200	8,000
Bottle shaken on the engine	200	140

A second experiment was made in a similar manner, but 0.01 per cent. of pepton was added to the water to hasten the development of the bacteria.

Sample.	Number of Bacteria Per c.c.	
	Initial.	After 18 hours.
Quiet bottle	78	1,900,000
Bottle shaken on the engine	70	342,000

These experiments show that agitation exercises a retarding influence upon the multiplication of bacteria, but that the slight shaking that water samples are liable to receive for a few hours during transmission is practically of little importance in its effect upon quantitative determinations of the bacterial contents.

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THE PRECISION OF THE SLIDE RULE.

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As employed in engineering calculations, the ordinary 10-inch slide rule is commonly considered accurate to one-half of 1 per cent., and for work of greater precision some other method of computation is thought essential. Repeated trials, however, have brought to the writer the conviction that this limit is too low. With care a good rule will give much more accurate results.

In support of this contention the following example is adduced. The data were laboratory observations of four variable quantities, a, b, c, d, and fifteen sets of observations were taken. It was required to compute the products ab and cd, and the ratios $ab : cd$ for each set. These were worked out on the different scales of a 10-inch and a 20-inch slide rule, and the results compared with those obtained by using two many-figure calculating machines of different patterns. The quantity a had four significant figures, b and c three, and d either three or four. The computation by logarithms would therefore be made with a four-place table.

When simple products or quotients are desired, the lower scales of the slide rule are naturally used for greater accuracy; but when a compound fraction of the form $abc \ldots / \ldots pqr \ldots$ is to be evaluated, the upper scales are generally more convenient. This is because the slide must often be shifted through its whole length when the lower scales are used, even though the sequence of operations is carried out to the best advantage. If intermediate products are desired, it is usually necessary to compute them separately, and if the remainder of the calculation is obtained from these values, the additional uncertainties of reading and resetting affect the result much more than if the computation were carried through at a single operation. This is illustrated by (3) of the table below, which should be compared with the figures just above in each column. In this respect the calculating machine has an advantage over the rule, for the inter-

mediate values can be read off and recorded as they appear on the figure wheels.

It is difficult to measure the comparative speed of the calculating machine and the slide rule, chiefly because the character of the operations is totally different. It follows from this that for a trustworthy measure of speed the computer should be equally skilled in the use of both machine and rule, and this can hardly be assumed as true for the average case. Tests of this kind also often omit an essential factor—the time required to record the result. Broadly speaking, the writer has observed that a computation carried out to a given number of places by rule will require half again as much time by machine. To get an additional place of figures by machine, twice as much time must be taken as in the first case by rule. This result, though not necessarily valid for all observers, testifies at any rate to the extreme rapidity of slide-rule computation, since it is a well-established fact that on four- or five-figure work machine computation requires from 35 per cent. to 50 per cent. of the time required with logarithms.

The following table summarizes the results of five series of precision tests. In the last two, the quantities m, n, p, q, contained five significant figures each. For such data the 10-inch rule is clearly inadequate, and only the lower scales of the 20-inch rule were used.

TABLE.

ERRORS OF COMPUTATION BY SLIDE RULE, IN FRACTIONS OF 1 PER CENT. OF THE QUANTITY COMPUTED.

	10-inch rule.	20-inch rule.
(1) Product ab of two four-place numbers, on lower scales (2 settings, 1 reading):		
Average error	0.041	0.026
Greatest errors	0.157 and 0 091	0.069 and 0 069
(2) Ratio $ab : cd$, on upper scales (4 settings, 1 reading):		
Average error	0.133	0.062
Greatest errors	0 349 and 0.226	0.181 and 0.135
(3) Product ab divided by product cd, all computed separately on lower scales (6 settings, 3 readings):		
Average error	0.079	
Greatest errors	0 198 and 0 177	
(4) Product mn of two five-place numbers, lower scales:		
Average error		0 037
Greatest errors		0.096 and 0.090
(5) Ratio $mn : pq$, on lower scales (average 4½ settings, 1 reading):		
Average error		0.046
Greatest errors		0 167 and 0.130

Of the computations entering the above table, five were exact, 63 showed a negative error, and 68 a positive error.

If unconfirmed, a number of trials not greater than the above would hardly warrant very definite conclusions; but since these are only typical of hundreds in the writer's experience, it seems legitimate to make the following deductions:

(1) For short calculations the upper scale of the 10-inch rule is reliable to one-quarter of 1 per cent. The lower scale is better than one-fifth of 1 per cent., and may generally be used instead of a four-place logarithm table. It should be observed that the upper scale of the 20-inch rule, and the lower scale of the 10-inch rule are graduated alike.

(2) For short calculations the lower scale of the 20-inch rule is reliable to one-tenth of 1 per cent., and may be used instead of a five-place logarithm table.

(3) If five places of figures are to be obtained, and the intermediate products are required, the 20-inch rule is not much faster than a machine, and is vastly more fatiguing.

In applying the above conclusions to practice, two things must be prescribed: the rule employed must be accurate, and the computer should be practiced in the estimation of tenths. Other than this, no unusual skill is required, nor is any claimed in the above tests.

A NEW ERA IN INTERIOR LIGHTING.

By CHARLES L. NORTON.

We have so long given to window glass the task of keeping out the wind and rain, while letting the light and warmth of the sky enter, that the intrusting of another task to this universal detail of our structures is a step which interests the whole community. The window is henceforth to be not only an opening through which light may enter, but a medium for sending the light in the direction in which it is most desired. Except where it is necessary to have windows through which to look, conditions of economy will soon forbid the general use of plane glass. The age of plane glass has passed, to be succeeded by an age of scientific diffusion of light.

If our windows be of plane glass, the best and brightest light in the room is on the floor near the window, and it is here largely absorbed and lost. If, however, we interpose in the beam of light as it passes through the window a suitable diffusing medium, we may divert the light from its original downward direction into others where it will be more effective. The ribbed, corrugated, ground, and figured glasses now coming into common use are diffusing media for accomplishing this end, and it is to them and to their uses that it is the purpose of this paper to call attention.

In the year 1883, Mr. Edward Atkinson reported the method of constructing English cotton factories to his associates, calling attention to the use of rough-plate or hammered glass for glazing factory windows, it being claimed that a better light was distributed within, a claim which appeared to him to have a sound basis. Reasoning upon the subject, he first proposed to make prismatic glass with a view to deflecting and diffusing the light, but finding that such glass would be very costly, and subject to some other objections, he turned his attention to the types of glass already in use, causing photographic images to be made of the diffused light. These images showed that the common ribbed glass, in use for obstructing vision, also diffused

light in a most effective way. He published the facts, and soon after many mills and works were either newly glazed or reglazed with ribbed glass. A discussion having arisen on the relative merits of ribbed and prismatic glass, it became necessary to bring the matter to a scientific basis.

In 1894 he brought the matter to me, and we have just completed a series of experiments begun at that time, to determine just what gain would arise from the use of the new window glass in a large way, as in the windows of mills, schoolhouses, and public buildings.

The extent of our knowledge on the matter in 1894 was certainly not large, and very few of my acquaintances of scientific bent believed in the practicability of any such scheme for improving the present conditions of lighting. I am quite ready to confess that I was so sure that the insertion of a sheet of ribbed or corrugated glass in a window would be attended by a loss of illumination, that I designed my photometer to measure negative instead of positive quantities, and had the pleasure of rebuilding it.

The materials available for use as diffusing media in windows are of two distinct types: first, the corrugated and figured sheet glass; and second, the carefully designed and moulded prisms. Figures 1, 2, and 3 indicate the distribution of light in a small room with the window glazed in the different ways. After considerable study we came to the conclusion that the only data that would be of value to us in forming conclusions as to the practical utility of the diffusing glasses must be obtained from the examination of a large room lighted by a single window, in which the several glasses might be placed in rapid succession. The outdoor surroundings, the amount of exposed sky, the angular height of obstructions and the depth of the reveal over the window may be altered by means of suitable curtains. The method of procedure followed in the recent tests for the Factory Mutual Fire Insurance Companies, under the supervision of Mr. Edward Atkinson, was as follows:

All the makers of diffusing glasses of whom we could find trace were requested to send samples if they desired to participate in the test. Nearly a score of samples were received in response to our circular letter, and a few samples were purchased.

The Physics Lecture Room in the Walker Building of the Massachusetts Institute of Technology, was placed at our disposal by the Institute, and it proved to be in every way a suitable place in which

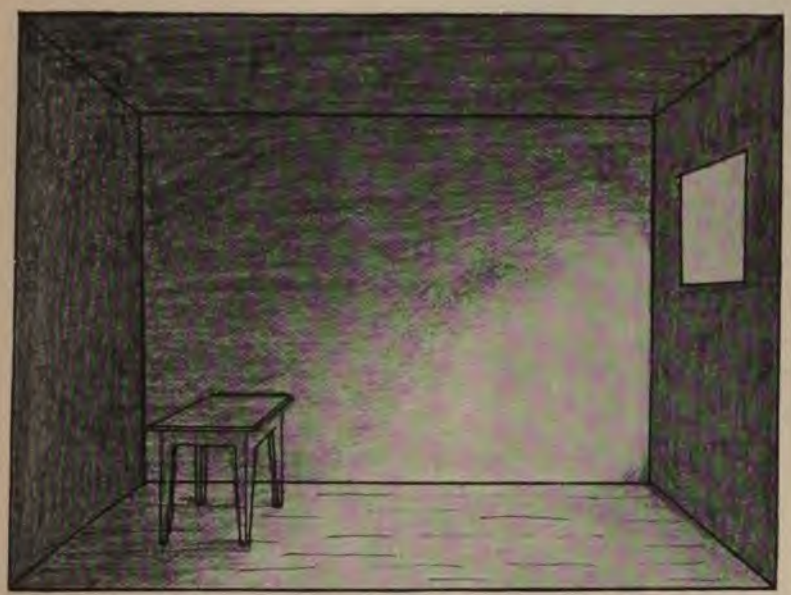

FIG. 1. — SKETCH SHOWING THE DISTRIBUTION OF THE LIGHT IN A SMALL ROOM WITH A WINDOW OF PLANE GLASS

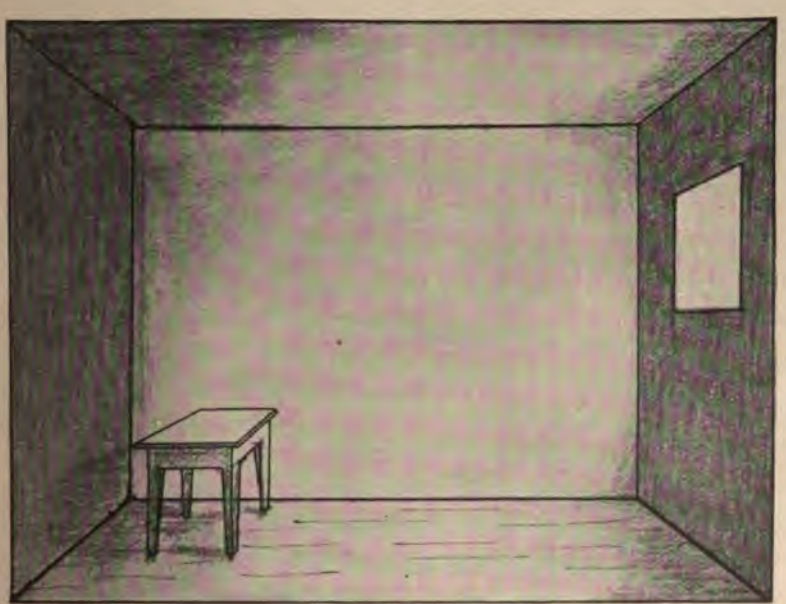

FIG. 2. — SAME AS FIGURE 1, WITH FACTORY RIBBED GLASS

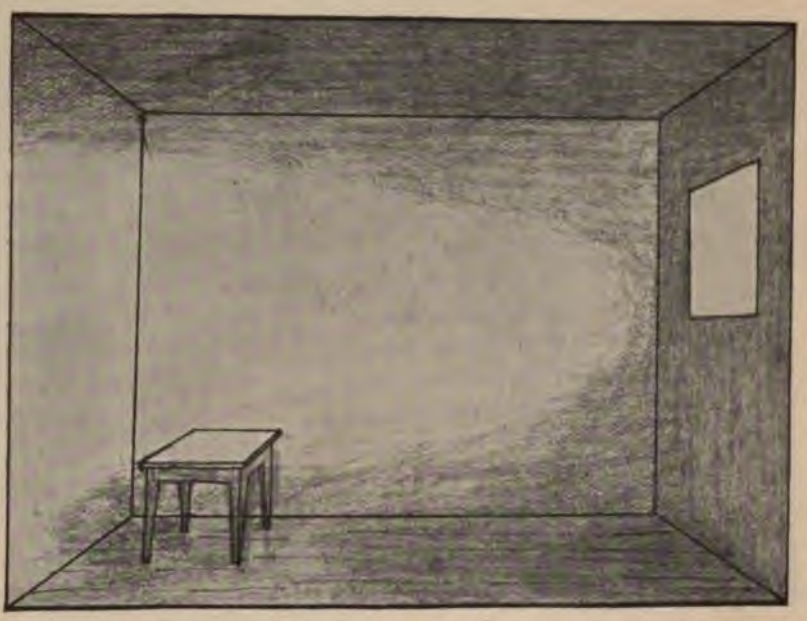

FIG. 3.—SKETCH SHOWING THE DISTRIBUTION OF LIGHT IN A SMALL ROOM, WITH A WINDOW OF PRISMATIC GLASS.

to make the tests. All openings by which light might enter the room were closed, except one window on the west side. This window was 12 inches square, and about 8 feet from the floor. The specimens of glass were inserted in the window in rapid succession, and photometric comparisons of the intensity of the light in the different cases were made. With each specimen the intensity of light was measured in a horizontal plane at the height of the table tops, observations being taken at stations 10 feet apart over the entire floor. The room was 50 feet wide and 40 feet deep.

The general conclusions to be drawn from the observations are: first, that in rooms of from 15 to 30 feet in depth, the ribbed or corrugated glasses will give an increase in the effective light at the level of the table tops, of from 200 to 500 per cent. Some of the prisms will do as well, but they are usually found to give too little diffusion in small rooms, especially where the windows are few and small.

Second, in rooms from 50 to 100 feet deep, the ribbed or corrugated glasses will often give an increase of effective light of fifteen times the original amount, and the prisms, especially when set in canopies, will increase the light in some cases to fifty times its origi-

nal effective strength. The determining factors in the case are the depth of the room, the angle of exposed sky, and the number and size of the windows. Stated broadly, the use of suitable prism canopies should make a basement as well lighted as a second story above it, glazed with plane glass.

The varieties of glass available for this work of diffusion are constantly increasing in number, and decreasing in cost. Among the less expensive are the ribbed or corrugated glasses. These may be had in different degrees of fineness of corrugation, in several thicknesses, and with the corrugations upon one or both sides. The finely corrugated glass with twenty-one ribs to the inch, has been known for several years as Factory Ribbed Glass, the name having been suggested by Mr. Atkinson. It is more sharply rolled than the glass with larger corrugations, and gives a better projection into deep rooms, but it accumulates dirt more rapidly than the coarser glasses.

There are almost numberless figured glasses, with a design of some sort worked in low relief on one side of the sheet. These act as excellent diffusing media in small rooms, but do not pitch the light up toward the horizontal enough to be effective in deep rooms.

The prisms made by three of the large companies were tested, though one sample came to hand too late to be given a complete series of tests. One make of prisms consists of sharp, carefully moulded triangular prisms, usually in tiles or plates about 4 inches square, and about $\frac{3}{8}$ of an inch thick. These are made of many different angles, and are installed only after careful consideration of the conditions under which the prisms are to be used. They are very satisfactory devices for projecting light in any desired direction in a room, with absolute certainty and with very little diffusion. A second prism differs from the first merely in that the lower surface of the prisms is curved instead of plane, giving a cross section which is substantially that of the lower half of the rib of the Factory Ribbed Glass. This gives a wider diffusion, but less concentration of the beam where it is desired to throw it in one direction, as is often the case in deep rooms. The third make of prisms is quite similar to the first type, except that the outer side, or back of the prism plate, is not plane but slightly sinuous in outline. Enlarged sections of the different diffusing glasses are shown in Figure 4.

The intensity measurements were made with a modified Cornu photometer, which served to compare the brilliancy of a piece of

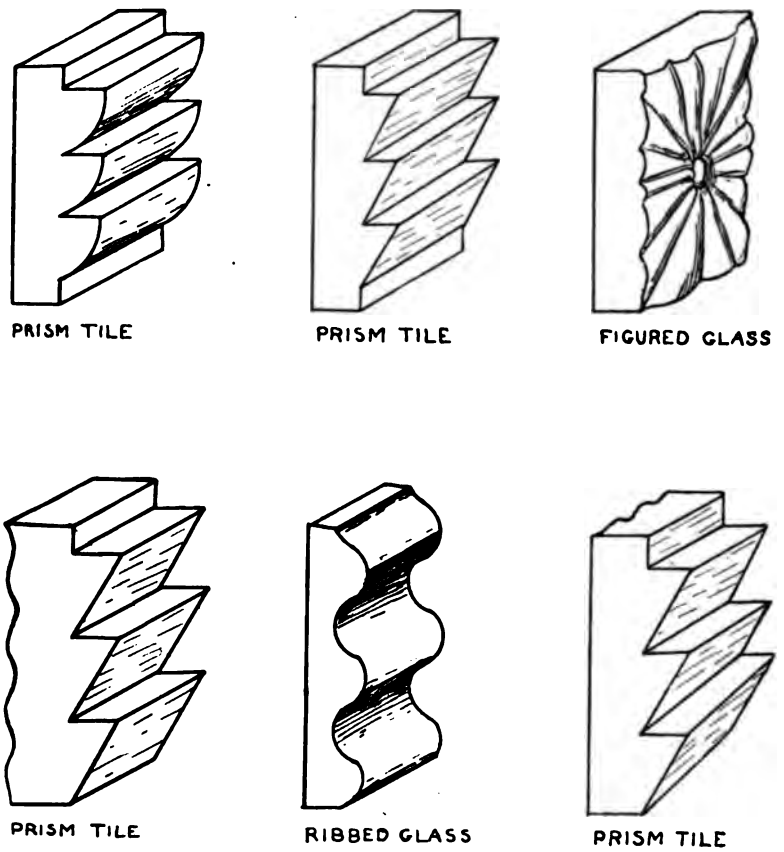

FIG. 4. — SOME DIFFUSING GLASSES.

white porcelain placed at the window with that of a second piece which could be moved to any desired point in the room. This method gave measurements which were expressed in percentages of the intensity of the light at the window, and were wholly independent of the strength of the light at the window at the moment of comparison. A radial arm, 15 feet long, centered just below the window, was also used to carry the white screen, but it was found that the results obtained with an arm of this length were of little value in furnishing data on the action of the different diffusing glasses in rooms of a depth greater than 15 feet. The reason for the apparent discrepancy between the observed value of the intensity at the back of the room 50 feet deep, and the values computed from the measurements made at a distance of 15 feet from the window, lies in the fact that a very

considerable and variable amount of light is reflected from the ceiling. It should be borne in mind that the light from the upper sash usually strikes the ceiling at a small angle, and that the reflecting power of even a dingy and rough ceiling is considerable at small angles. The glass which throws the strongest beam directly toward the back of the room may not furnish as satisfactory an illumination there as one which throws a more feeble beam directly toward the back wall, but adds a considerable amount to it by reflection from the walls and ceiling. It was therefore deemed better to measure the intensity of the light at a sufficient number of stations, and make an intensity map of the room for each kind of glass.

The examination of the different samples of glass showed at once that their usefulness lay largely in different fields, as was suggested above. In shallow rooms now fairly well lighted, the figured glasses give a soft, well-diffused light with an absence of glare and a material strengthening of the light in the rear portion of the room. As we study rooms 30 feet or so in depth, we find the figured glass gives too little light near the back of the room. Evidently something is here needed to throw the light further up toward the horizontal, as well as to give a nearly hemispherical diffusion, and the Factory Ribbed Glass has here proved its value. The action of this glass is very interesting to me. It exists, not because of its diffusing properties, but because it is an obstruction to vision without many of the faults of the ground and painted glasses which were much used earlier. It was never designed to be a thorn in the flesh of the makers of prismatic glass, yet such, I fear, it has been for some time past. The fact that a cheap rolled glass can be of merit as a diffusing medium seems to be beyond the belief of the makers of the carefully moulded prisms. The relative efficiency of the rib and the prism is largely dependent upon the size of the sky angle to which they are exposed, and the depth of the room which they are to light. If the light came from one point in the sky, and was to be used at only one point in the room, the angular prism of precise form would unquestionably be of the greatest value, and it is in the cases where those conditions are most nearly true that the prism finds its greatest field of usefulness. But in cases where the light comes from a broad expanse of sky, and is desired in wide diffusion throughout a large room, it is not easy to define the action of the different types of rib and prism. Stated broadly, the efficiency of the rib falls off more rapidly than that of

the prism as the sky angle decreases, and as the depth of the room increases.

Let us now look at the changes which we may bring about in some particular cases by the use of diffusing glass, instead of plane glass. Take first the ordinary Boston type of school room, 28 x 32 feet, with windows on two adjacent sides. We have two conditions to consider, the presence or absence of the sun at the window, causing a great difference in the amount and distribution of the light. Without the sun, we find ordinarily that the half of the room nearest the windows is fairly well lighted. The exception is the occasional city school, with its tall neighbors in close proximity to its too few windows. It is desirable when the sun is not shining upon the windows to strengthen the light in the rear half of the room. On the other hand, when the sun is shining through the windows, the half of the room farthest from the windows is fairly well lighted, and the chief source of complaint is the too great brightness near the windows. Resort is usually had to window shades of greater or less opaqueness to cut off the light as a whole, for the benefit of the pupils within a few feet of the windows. The result is that the back of the room is insufficiently lighted at all times.

Suppose, however, we should put a suitable ribbed or prismatic glass in the windows. It is hardly practical to so adjust the glass as to give to those near to and far from the windows exactly the same strength of light, but the ratio of intensities may readily be changed from 20 to 1, to 2 to 1.

Consider the case of a large mill room with large window areas. We are here much less concerned with the amount of the diffusion from any one window, since the number of windows is so great as to give a satisfactory diffusion in those parts of the room which are within 20 feet of the windows. The ribbed glass and prisms act in such a room as deflecting devices, to carry the excess of light near the windows bodily back into the middle of the room. I have in mind a mill with two wings of a similar exposure. One is glazed with plane glass, the other with diffusing glasses, and on any cloudy afternoon you may find the plane glass wing all gaslight, while the other is amply lighted with diffused daylight. It is hardly necessary to add that as I write, the further substitution of diffusing glasses is being carried out in this mill.

In the large city stores we have still another condition of affairs, for here we meet usually with a deep, narrow room, lighted only from one end, with a window the full width of the store. We may usually count on finding the lower half of the window obstructed by merchandise. The city store rarely has more than a limited sky angle. The one thing eminently suited to improve the light here is the prism, especially if it can be set in canopies over the sidewalk. The thousands of square feet of prisms which have been installed within the last four years in the stores of our large cities attest the real commercial value of this device for this work.

In offices and in small rooms we have still another set of conditions to meet. Except where the sky angle is very small, we need here essentially a diffusion of as wide an angle as possible, with a much less regard for the upward tipping of the beam. We find here that the glasses worked with a raised pattern are of especial value. Some of them are of pleasing appearance, and are known as "Florentine," "Maze," "Arabesque," and "Figured" glass. There are many others by several makers, but these are typical of the whole class.

Skylights have long been a source of trouble when the sun strikes full upon them, but the substitution of a diffusing glass scatters all about the room, and puts to good use the light which otherwise fell so strongly upon some one spot as to make imperative the use of some sort of an opaque shade.

It is to be regretted, but it is certainly true that strong objection is often made to the "shut in" feeling which some people experience in rooms glazed wholly with diffusing glass. Repeated legislative action has been urged to prohibit the use of this glass in factories, and as a result it is now customary to confine the use of diffusing glasses to the upper sash. A more serious objection comes from the unpleasant and often unbearable glare of the glass when in the bright sunlight. The prisms are especially bad in this respect, but a remedy may be found even with them, in the use of a thin white cloth shade, to be drawn only when the sun strikes the window. We thus have the light at its maximum in dull weather, and can yet temper its brightness when it is necessary to save the eyes of those working in direct line with the light.

The substitution of ribbed or figured sheet glass for plane gives rise to no new mechanical problems, but the setting of the prisms in small tiles has called for a great expenditure of time and money. It is not

quite certain that the present methods of holding the small tiles in metal frames by means of a cement filling or by an electrolytic deposit of copper are wholly satisfactory. The one is not easy to make tight while the other is so close a fit that the greatest care in relieving the frame from all strain is necessary, or the tiles become cracked or broken. The chief reason for making the prisms in small tiles has been heretofore the difficulty of rolling large sheets of prisms without deforming. The use of glass in large sheets for canopies over the sidewalks is prohibited by considerations of the safety of those passing underneath, so small tiles in stout metal frames must continue to be used for this work.

The action of prisms when set in canopies over a window is two-fold: first, as in the ordinary setting, to give an upward tip to the light; and second, to actually send through the window more light than would otherwise enter through it. Especially in narrow streets where the angle at which the light strikes the vertical is small, a canopy projecting into the street, even if of no greater area than the window will have incident upon it much more light. Being composed of total reflecting prisms, a canopy throws into a room almost all the light which falls upon it. Unlike the vertical prisms which are active by virtue of their refractive power, these total-reflection prisms have uppermost the surface through which the light enters, and they are more seriously affected by accumulations of dust and dirt.

The diffusion of direct radiant heat from the sun or from the sky follows much the same lines as in the case of light, but so large a proportion of the heat which enters a room comes in ways other than by direct radiation, that the main effect of the diffusing glasses is to prevent the local overheating of those portions of a room which are exposed to direct sunlight.

The criticism which has been offered several times, that the use of glass which prevents the direct entrance of beams of sunlight was injurious to the health of those living in rooms so glazed, is of course sheer nonsense. The action which light has upon disease germs can be operative as well through a diffusing glass as through plane glass.

In conclusion, we may safely predict a field of usefulness for the diffusing window, in improving the light in many rooms now dimly lighted, in making profitable the construction of rooms of greater depth, and in allowing of the closer approach to one another of tall buildings, with a resulting economy in land.

TRADE WITH EUROPE.

By WILLIAM H. LINCOLN.

Read January 14, 1901.

I HAVE been requested to speak to you this evening upon our export freight to Europe, or as I shall interpret it, our commerce with Europe. It will be my purpose, so far as I am able, to divest the subject of dry statistics and to explain the nature of this trade, the great developments that have taken place, and the rapid growth under favorable conditions. It is this trade that has given such wonderful prosperity to the country during the past three years, that put in motion all the wheels of industry, that has brought large earnings to our great railway lines, that has made money so abundant and created vast wealth for this country. It will be interesting and profitable to trace the source of these great benefits. It is a large subject, capable of almost indefinite expansion, of widest scope, and it will be possible only to deal with the most important branches of the trade. I am sure there is no more useful, interesting, or fascinating study than that which relates to the origin and growth of a trade with foreign peoples.

The character and extent of the commerce of a people determine in a great measure its influence in the world, and upon it depend its wealth and prosperity. The first steamship that crossed the Atlantic started from New York for Liverpool as far back as in 1819. This event was the forerunner of a new era in trade, revolutionizing former methods. And what progress has been made since that time! From wood to iron and steel, from sail to steam, from small craft to monsters of the deep, the ocean is now but a river, and the mighty steamships serve as a bridge to cross it. The terrors of the sea hardly have any existence, so swift, so certain have become the passages across it. The electric telegraph — the cable, have brought the remotest corners of the earth to our doors. Space and time are annihilated; merchandise is bought in this country; the freight engaged from point of shipment

in the West to its destination in Europe, and within a few hours sold in Europe at a price to yield a small commission — a fraction of a cent per bushel on grain. What facilities for human intercourse, for the transaction of the business of the world, and requiring improved methods, a firmer grasp of situations, a keener insight, more enterprise, more effort, and greater sagacity. The strife is more earnest, and competition closer. The country has been startled by the enormous growth of our export trade. The statistics have not been compiled for the entire year past, but I am able to give them for the eleven months of 1900. The total imports were $760,000,000, of which $139,000,000 were from the United Kingdom, and $93,000,000 from Germany.

The exports were $1,380,000,000, of which the United Kingdom received $535,000,000, and Germany $179,000,000, so that it will be seen that the United Kingdom purchased of us $400,000,000 in excess of our purchases from them, and this in eleven months. It is safe to say, as December is an active month, that the United Kingdom becomes our debtor to the extent of $500,000,000 per annum. As might be expected, our exports consist of food products and raw material. England is becoming more and more dependent upon other nations for her food supplies, and with this country now entering upon a period of close competition in the markets of the world in manufactured goods, it would seem that she has nearly reached the maximum of population she will be able to support. Just here it may be interesting to note that the United States produces

80 per cent. of the world's cotton.
80 per cent. of the world's corn.
25 per cent. of the world's wheat.
30 per cent. of the world's meat.
30 per cent. of the world's iron.
40 per cent. of the world's steel.
33 per cent. of the world's coal.

and more startling than all, her manufactured product is greater than England, France and Germany combined. Our export of manufactured goods amounted to $25,000,000 monthly in 1898, now increased to $40,000,000. In thirty years our manufactured output has increased from $3,700,000,000 to $13,500,000,000. These facts, indeed, fix our status to be the superior and favored nation of the world. Let us now examine somewhat in detail our trade with Europe, and these facts relate to eleven months of business.

GRAIN EXPORTS.

Corn, 152,000,000 bushels, value, $67,000,000.	To the United Kingdom, $32,000,000.
Wheat, 80,000,000 bushels, value, $58,000,000.	To the United Kingdom, $42,000,000.
Oats, 30,000,000 bushels, value, $9,000,000.	
Flour, 11,500,000 barrels, value, $43,000,000.	To the United Kingdom, $39,000,000.
Cotton, 6,000,000 bales, value, $260,000,000.	To the United Kingdom, $120,000,000. Germany, $68,000,000.

The supremacy of the United States as the greatest contributor to the world's meat supply, the fact that our exports greatly exceed that of any other country, that our animal product is second only in importance to cereal culture, render the study of this product of unusual interest. The intimate connection between livestock and corn must be borne in mind in order to understand the full import of the meat trade. It is estimated there are 40,000,000 swine slaughtered in the United States in a year, and in the raising of these there is a consumption of 800,000,000 bushels of corn, or one-third the entire crop.

As will be seen by the figures, England is the largest consumer of our meat products; in fact, nearly the whole of this business is confined to that country. The chief feature of the meat importation into Great Britain has been the change from the importation of salted to that of fresh meat. From 1871 to 1898, the quantity of salted meat declined over 25 per cent., while that of fresh meat increased almost 140 fold. Importation of hams into the United Kingdom has also been marked by a rapid displacement of Danish and German hams by the American product. In 1871 Holland and Germany furnished 33 per cent. of the total amount as compared with 57 per cent. from the United States. In 1891 the percentage was one-third of 1 per cent., and that of the United States 98 per cent. Since that time the trade has been monopolized by the United States and Canada. The United States furnished 94 per cent., and Canada 6 per cent. in 1898. In the exportation of mutton to Great Britain, we have taken no part. Of the total importation of 1898, 3,314,000 hundred weight, valued at $24,000,000, 57 per cent. was furnished by Australia, 33 per cent. by Argentina, and 8 per cent. by Holland. In this connection it may be interesting, especially as connected with the wool supply, to note that it is computed that there are 110,000,000 sheep in Australasia, 74,000,000 in Argentina, and 38,000,000 in the United States. The carcasses are frozen at point of shipment, and shipped by steamers especially fitted for the business.

FRESH MEAT.

The shipment of fresh meat furnishes a striking illustration of how a trade can be created and increased by the adoption of improved methods. The first shipment of fresh meat from this country was made in 1876 to Liverpool. The system of refrigeration adopted was crude as compared with that now in use. Ordinary ice boxes were constructed, and these were replenished with ice during the voyage. The meat frequently landed in a damaged and mouldy condition, especially in hot weather, causing large losses to shippers. The people were naturally prejudiced against American meat transported such a distance, and it required many years of persevering effort and greatly improved methods of transportation to overcome that prejudice. Many years passed before the ammonia process of cooling the refrigerators was perfected. There is now no complaint in regard to the condition of the meat on arrival. The shippers have established their own meat shops in the large centres of trade in the Kingdom, and the trade is now conducted at a saving in expense and with greater efficiency. There are now shipped on many of our large steamships 5,000 quarters of beef, the equivalent of 1,250 head of cattle. This trade has become of great importance to the steamship lines and to the country.

In recent years Australian beef has vigorously competed with the American product, and it now forms 20 per cent. of the whole product. The statistics for the eleven months of 1900 are as follows:

EXPORTS.

Bacon, 410,000,000 lbs., val., $32,000,000. United Kingdom, $27,000,000. Germany, $1,300,000.
Hams, 168,000,000 lbs., val., $18,000,000. United Kingdom, $17,000,000. Germany, $200,000.
Pork, 107,000,000 lbs., val., $7,000,000. United Kingdom, $5,000,000. Germany, $550,000.
Lard, 480,000,000 lbs., val., $32,000,000. United Kingdom, $12,000,000. Germany, 11,000,000.
Fresh beef, 300,000,000 lbs., val., $26,000,000, all to the United Kingdom.

Our total shipments of provisions amount to $170,000,000, and in 1889 they were $104,000,000. Fresh meat, 1890, $13,000,000; 1899, $23,000,000.

The shipment of fresh meat has caused a decline in canned beef and salt beef. The exports of canned beef have declined from $6,000,000 in 1890, to $2,500,000 in 1899; salt beef from $4,200,000 in 1890 to $1,080,000 in 1899. On the other hand, in salt pork there has been an increase from $4,700,000 in 1890, to $7,900,000 in 1899, and of pickled pork 18,800,000 pounds in 1890, to 91,700,000 in 1899.

To illustrate the increase in lard and hams exported to Europe:

Lard.		Hams.	
1890.	384,000,000 pounds.	1890.	$7,000,000.
1899.	626,000,000 pounds.	1899.	19,000,000.

In butter and cheese, nearly all of which is for Great Britain, there is a marked decline, especially in cheese: 1890, $7,300,000; 1899, $2,000,000.

No doubt this has been caused in part by improper or careless management of the business. The packages in which cheese is shipped are very frail, incapable of much handling, and as a consequence they are landed in bad condition, and the contents suffer damage. Then in the summer season these articles deteriorate, and unless shipped in refrigerators are delivered out of condition.

The imports into England of our provisions are rapidly increasing with increase of population, and also because the consumption *per capita* has increased 20 per cent. This is due to the lower price; fresh meat is now selling at one-half the price it was before our meat was imported.

LIVE ANIMALS.

There is no more interesting part of our foreign commerce than that relating to our live cattle trade. In 1875 I engaged for the steamer *San Marcos* the first shipment of live cattle from this country to Europe. That year 300 head were shipped, and we have been exporting for a good many years 300,000 head per annum, valued at $28,000,000, all to the United Kingdom. The increase is due to better facilities, improved fittings, etc.; the losses used to be heavy at times. In 1889 the Argentine Republic began to export in competition with us, so that in 1898 there were exported from the United States 369,000 head, or 65 per cent., and Argentina 89,000, or 16 per cent. Canada also exports live cattle.

It is interesting to note the changes that have taken place in the cattle producing countries of Europe. In 1871, which was before we exported any cattle, the total imports into Great Britain were 218,000 head. Holland was easily the first in supplying this trade, with 43 per cent., Germany second, with 31 per cent. of the whole. The traffic was thus essentially a Western European one, and the sea voyage was short. The relations of these countries remained approximately the same for some time until Denmark increased her shipments, and after 1876 that country became the chief European country of supply. The exports

from Denmark, however, rapidly declined after 1883, as did the whole European export to the United Kingdom, and entirely ceased in 1893. The chief feature of the live cattle trade has been the shifting of its incidence from Europe to America.

SHEEP.

The importation of live sheep into Great Britain is of declining importance. In 1878 892,000 head were imported, and in 1898 664,000, and value of sheep also has declined. The same process took place as in the case of cattle. The source of supply is now from United States, Canada, and Argentina — the latter had not made any shipments until 1890 — and at present ships 64 per cent. of the entire quantity, and the United States 22 per cent.

HORSES.

This trade is of comparatively recent origin, principally on account of the low prices of horses in this country. The exports the past eleven months have amounted to 27,000, valued at $4,000,000.

LEATHER.

I have taken quite an interest in the growth of this trade, because it has developed from very small beginnings. The first shipments were of sole leather, and now we export largely of finished leather. We exported last year 27,000,000 pounds of sole leather, valued at $5,000,000, of which England took 4,500,000, and finished leather having a value of $12,000,000, of which $9,000,000 went to England. We also shipped to Europe boots and shoes valued at $1,250,000.

ILLUMINATING OIL.

It will surprise you probably to hear that there were exported from this country to Europe 650,000,000 gallons of refined oil during the past year, valued at $40,000,000, and 112,000,000 gallons of crude oil, valued at $6,000,000.

MACHINERY.

Included in our exports to Europe is a large variety of manufactured goods, machinery, scientific apparatus, etc. Sewing machines, $2,500,000; typewriting machines, $2,000,000; telephone and electrical apparatus, $4,500,000, the amount having doubled in two years.

IRON AND COAL

A marvellous change has taken place in this country in respect to those two great sources of national wealth. The iron ore production in 1894 was 12,000,000 tons, and in 1899 it was 24,000,000 tons, as against 14,000,000 tons in Great Britain. Our product of coal was 230,000,000 tons, while Great Britain's was 220,000,000 tons. Our total exports to Europe of products of iron and steel were $120,000,000: Steel rails to Europe, 27,000 tons; hardware, $4,000,000; structural iron and steel, $3,500,000; wire, 160,000,000 pounds, $4,000,000. Agricultural instruments valued at $10,000,000 were exported to Europe. These figures show that the leadership has passed to the United States in the production of those raw materials upon which the manufacture of iron and steel depends. Nearly one-third of the world's output of iron ore has passed to the United States. Not only that, but the prices are lower in this country than in Europe. What interpretation is to be put upon these facts as outlined? It means industrial power at home and commercial prestige abroad. It means vast increase of national wealth. Hitherto agricultural products have been our main exports, and now we are to add the manufactured products. We are only at the beginning of our resources. The turning of this tide marks the end of the old and the beginning of a new era in our history. Hitherto, we have progressed slowly and gradually. That progress has been marked by revulsions in trade, — advance and decline — but during the past three years the nation has advanced by leaps and bounds, and we have become the great commercial nation of the world; not by accession of foreign territory, but by the development of our own resources. The enormous wealth that has been poured into this country has led to great industrial development. Companies with capital of hundreds of millions have been created, and the result is increased production at minimum cost.

I cannot close without referring to one branch of industry in which we have been sadly deficient — ship-building and our merchant marine.

There are dangers that will confront us. The history of other nations that have been great and powerful in their day reveals to us the effects of the intoxication of success, and the demoralizing influences of luxury and wealth. The two great counteracting forces that are at work in this country, and that will enable us as a people to overcome the temptations that beset us, and to pass through the ordeal in triumph and safety, are education and religion.

ON THE DRAINAGE, RECLAMATION AND SANITARY IMPROVEMENT OF CERTAIN MARSH LANDS IN THE IMMEDIATE VICINITY OF BOSTON,[1]

By WILLIAM LYMAN UNDERWOOD, Lecturer in the Massachusetts Institute of Technology, and Member of the Board of Health of Belmont.

It has long been recognized that the existence of "wet, rotten and spongy lands" in the near neighborhood of towns and cities may constitute a menace to the public health, and special attention has been drawn to such areas within the last three years, since it has been established with tolerable certainty that the mosquitoes for which they too often furnish a breeding place may become effective vehicles of malarial or intermittent fever. In almost every town in the state are to be found undrained areas of wet, sour and swampy lands which in many ways are a nuisance and more or less injurious to the public health. Pools of stagnant water are frequently found upon them, in which may be bred myriads of mosquitoes whose existence in any neighborhood is a damage quite apart from the fact that they may in all probability become the effective carriers of the germs of intermittent fever.

From such areas arise foul odors of decaying vegetation, and in the colder months of spring and fall the air, heavily laden with moisture, tends to impart to the surrounding neighborhood a cold and penetrating chill detrimental to the public health. Frequently these lands cover a very large tract whose ownership is divided among many individuals; very often the territory may cover lands lying in separate, though contiguous, towns.

The question arises, how can these conditions be remedied or the dangers from them be minimized? If it is possible to drain these spongy lands and so bring the soil back to a sweet and wholesome condition, who is to do the work, and at whose expense is it to be done? An individual owner generally cannot work to advantage unless he has the coöperation of his neighbors. How to bring about a unanimity of

[1] Read at the Quarterly Meeting of the Massachusetts Association of Boards of Health, Boston, January 24, 1901.

purpose and action on such a question is often a very difficult problem to solve, especially when it involves the possibly conflicting interests of two or more different towns. While it may in most instances be impossible to obtain concerted action through individuals, there is fortunately, if properly applied, a method by which much good may be effected, and that is through the local Board of Health — if the lands in question lie within one town — or by the united action of the Boards of Health of two or more towns whose interests are involved, provided it can be shown that the areas in question are detrimental to the public health. The laws which the State of Massachusetts has enacted to deal with such conditions are positive and plain, and briefly as follows:

Lands which are wet, rotten and spongy, and offensive to persons residing in their vicinity, or which are injurious to the public health, may be deemed a nuisance, and upon a hearing and petition, such nuisance may be abated. A Board of Health may also determine who shall bear the expense of making such improvements and the keeping of them in repair, whether it shall be the city, town, or persons, benefited thereby.

As a single illustration of what has already been accomplished along these lines in one case, and to show that still further steps seem absolutely necessary for the safety of the public health, a tract of territory will be considered, situated within five miles of the State House in Boston, lying in and between the cities of Cambridge and Somerville, and the towns of Arlington and Belmont, and known as the "Fresh Pond Marshes." It is the purpose of this paper to describe and illustrate the condition of these marshes as they now exist, and as they existed before certain sanitary improvements recently made by the Boards of Health of Belmont and of Cambridge had been carried out. In order to give a clear idea how these conditions were brought about, it will be desirable to state a few facts concerning the early history of the Fresh Pond Marshes.

In 1856 the Cambridge Water Company first began to use the waters of Fresh Pond for the city supply, and their charter also granted them the right to take the waters from Little and Spy Ponds and Wellington Brook. During that year F. W. Bardwell (a member of the Lawrence Scientific School) was employed to ascertain the amount of water available for the city's use. He made careful calculations and found that the average discharge from Fresh Pond and through Alewife Brook (see map) was a little over 2,000,000 gallons daily. From Spy

and Little Ponds and Wellington Brook, it was about 10,000,000 gallons daily. He reported that by building a dam across the culverts under the Lexington Branch Railroad the waters from these ponds and the brook could be forced back into Fresh Pond. It is not clearly shown just when Fresh Pond began to be supplied in this way, but it was probably sometime before it became necessary to do so. In a report of 1870, however, the following appears:

"A new gate and gatehouse have been built at the outlet of Fresh Pond, and flashboards have been erected on Alewife Brook where it passes under the Lexington Branch Railroad. These flashboards were rendered necessary, not only to secure the water flowing from Spy and Little Ponds, by conducting it into Fresh Pond, but also to enable the fish to escape from the pond to the ocean. There had been no water flowing from Fresh Pond for several months, while there was a constant flow from Spy and Little Ponds. By the dam at the railroad crossing, the tide is effectually shut out from all the ponds, and the water from Spy and Little Ponds is carried directly into Fresh Pond."

This system was evidently used until 1873, when two sewers were allowed to empty into Alewife Brook — one at Spruce Street, and another at Concord Avenue. In order to avoid contamination of the water supply of Cambridge by their sewage, the outlet of Alewife Brook was then permanently closed by filling in with dirt, and sheet piling was driven in across the brook at Concord Avenue. As a further safeguard, tide-gates were built at Broadway in Somerville, to prevent the tide-water from backing the sewage upon the meadows. As Cambridge, however, could not afford to lose the amount of water which she had been getting from Little and Spy Ponds and Wellington Brook, she built in 1875 a conduit to carry this supply directly from those ponds and Wellington Brook into Fresh Pond. (This is shown upon the map.) For a number of years this system appeared to be satisfactory; but with the rapid increase in the population of Cambridge, it soon became evident that a larger water supply was necessary. It also became clear that the conduit water was being badly polluted, for Wellington Brook, with its drainage area of 2,500 acres (the greater part in a state of high cultivation and heavily manured), was becoming a serious danger. In 1879 the Cambridge Water Board had borings made all over the territory between the meadows and Fresh Pond. As a result they found a rapid undercurrent of water setting from the marshes to the pond, and in their report for that year they stated that it was very important

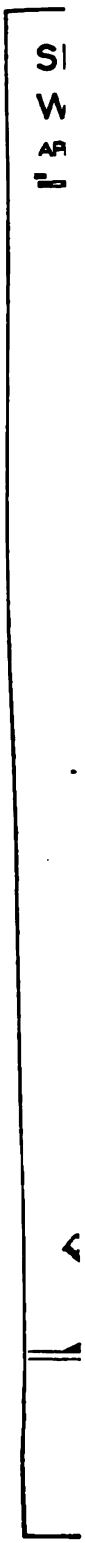

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FIG. 1. — A 10-inch pipe located in Belmont, 700 feet from the Cambridge line. Through this pipe was flowing, on July 27, 1900, all the water from Wellington Brook at that time. The bridge, on Hittinger Street, was being repaired and the water was temporarily cared for in this way. It will be seen that a much smaller pipe would have answered the purpose. (Compare this with Figure 4 taken on the same day.)

FIG. 2. — Looking southeast, from bridge on Hittinger Street, July 27, 1900; showing pool in Belmont into which the water from the 10-inch pipe shown in Figure 1 was flowing. This pool was 3 feet deep, and well indicates the lack of proper drainage.

FIG. 2*a*. — The same place shown in Figure 2, Nov. 22, 1900, and after heavy rains. It will be seen how the water has been lowered in spite of the rains and drawn off by simply clearing out the channel in Cambridge territory. On the right bank will be noticed the roots of the rushes which are to be seen in Figure 2 growing luxuriantly.

FIG. 3. — July 27, 1900, looking east from Wellington Street. The channel of Wellington Brook is filled with rushes. Within half a mile, in Belmont, is a schoolhouse from which there are more absences relatively from sickness than from any other school in that town.

FIG. 3*a*. — November 22, 1900, the same view as in Figure 3, but after the new channel had been made.

FIG. 4. — July 27, 1900; a 4-foot pipe and culvert under the Fitchburg Railroad and Central Massachusetts tracks, 1,200 feet below the 10-inch pipe shown in Figure 1. This pipe was standing almost full of water; while the 10-inch pipe further up the stream was not half filled, though carrying all the flow of Wellington Brook. At the lower end of the culvert rushes were growing and filling the channel. These and other obstructions further down the stream were holding the water back and keeping the pipe full.

FIG. 4*a*. — November 22, 1900, from the same point as Figure 4, but after the channel had been cleaned out. It will be seen that the pipe is but half full of water, though the view was taken after a heavy rainfall. When the brook was first cleared out, there were only five inches of water flowing through the culvert.

FIG 5. — July 27, 1900. An obstruction of willow trees growing directly in the bed of Wellington brook. The surface of the water is covered with a thick scum of duckweed, with the exception of the dark space in the centre, into which, just before the picture was taken, a stone had been thrown.

FIG. 5*a*. — November 22, 1900. From the same point as Figure 5, but showing the new channel. Just beyond the willow tree and to the left, was situated formerly the gateway that carried the water through the conduit into Fresh Pond. (See map.)

FIG. 6. — July 27, 1900. A stagnant pool, the surface of which was covered with green scum. After the new channel was constructed this pool was lowered about 2 feet. In the winter of 1899–1900, on a number of occasions, the water in this vicinity rose so high that it covered the roads and prevented children living at Blair's house (see map) from attending school.

FIG. 7. — July 27, 1900. The mouth of Wellington Brook where it enters Little River. From this point to Wellington Street the new channel was constructed. It will be seen, by referring to the map, that here the stream had become completely obstructed. For some distance the water of the Brook had to soak its way through the soil to Little River.

FIG. 8. — December 8, 1900; looking east, and showing conditions still existing at the worst spot on the marshes. In this section there are 65 acres, bounded on the north by the tracks of the Fitchburg Railroad; on the east by the tracks to the factory of the Boston Packing and Provision Co.; on the south by Concord Avenue; and on the west by high land, — from which this view was taken. Most of this territory is under water throughout the entire year. Formerly, the greater part of it was covered with a growth of maple trees; but these have all been killed by the gradually-rising water. At points *A* (see map, directly under 6) and *B* (more to the right) culverts used to drain this section into Wellington Brook; but now these waterways have been filled in and the only outlet is at *C* (see map, point on railroad tracks north of Artificial Pond). From the north side of the Fitchburg Railroad tracks, at this point, the water has to find its way across the marshes as best it can, for there is no channel for it.

FIG. 9. — The old tide-gate house, at Broadway, in Somerville; built in 1872 and abandoned in 1896.

FIG. 10. — Looking north from Powder House Boulevard, and showing marshes between Broadway and the Mystic River. If tide-gates were constructed at the point where the foot-bridge crosses Alewife Brook (see map) near its junction with the Mystic River, this marsh land could be changed into a lagoon, in which the brook waters could be stored during the period of high tide in the river. By this means it is probable that the water-table of the Fresh Pond marshes could be lowered 3 feet.

FIG. 11. — The shore of Artificial Pond. (See map.)

FIG. 12. — A view near the marshes, showing the agricultural possibilities of this loca

FIG. 13. — The unreclaimed portion of the marshes as it exists to-day. Looking south-east from the Massachusetts Central tracks, December, 1900. Within half a mile of this swampy area there are located 1,161 dwelling houses; 128 of these are in Belmont, 201 in Arlington, 307 in Somerville, and 525 in Cambridge.

FIG. 14. — Looking east along the south bank of Wellington Brook, in Belmont, about a quarter of a mile above the point where it passes under Concord Avenue. The brook is hidden by the shrubbery to the left. In the lower right-hand corner is seen a portion of a lily pond, and in the background is a meadow kept sweet, dry and fertile by means of proper drainage.

FIG. 15. — The lily pond, a part of which is shown in Figure 14. Here are grown aquatic plants, including six hardy varieties of water lilies that bloom from May to October and require no special care. In the water are hundreds of gold-fish that feed upon the larvæ of mosquitoes and serve to keep this insect pest in check. In such ponds these fish thrive and multiply, surviving even the coldest winters of the locality.

Figures 14 and 15 illustrate what might be accomplished on the Fresh Pond marshes by proper drainage and care.

that these meadows should be kept clean in order to avoid contamination of the public water supply. The marshes are to-day in a worse condition than they were then, and if the opinion of the Water Board was correct, must still menace the purity of the waters of Fresh Pond. To avoid further contamination and to meet the growing demand, Cambridge in 1887 began to take its main supply from Stony Brook in Waltham, and Little and Spy Ponds and Wellington Brook were abandoned as sources of water supply.

The condition of the meadows at this time from a sanitary point of view, was far from satisfactory. Naturally, the channel of Wellington Brook, through disuse, had become considerably obstructed below the point where its water was diverted by the conduit. Rank weeds and other growing vegetation in some places completely filled the bed of the stream. For a number of years the farmers had entirely neglected the land in this vicinity. Prior to 1880, and as long as the ice business of Fresh Pond was in a flourishing condition, these marshes were cared for, the channels of the brooks were annually cleaned out and the whole meadows thoroughly ditched. Heavy crops of meadow hay were harvested from them and found a ready market with the ice men, who used large quantities for packing in their ice houses. The Fresh Pond Ice Company alone bought 100 tons of hay a year, frequently paying as high as $20 a ton for it. In 1888 the last ice house was removed from the pond, and from that time until the present (a period of some twelve years) no attention has been paid by the owners to the drainage of this large territory. Year by year the water has been rising higher and higher upon the fields until stagnant pools have come to exist all summer long, and offensive odors of decaying vegetation are given off, where twenty years ago crops of good meadow hay were cut annually. Malaria has crept in, and the whole district has threatened the health of the surrounding towns. It was this condition of affairs that the Board of Health of Belmont was called upon to investigate.

It was at once apparent that the town by itself could take no effective steps to alleviate the trouble, as the backing up of the waters of Wellington Brook upon Belmont lands was due to obstructions further down stream within the limits of Cambridge. Coöperation with the Board of Health of that city seemed to be the only remedy, and early in the fall of 1900, through the united action of the Boards of Health of Cambridge and Belmont, a considerable area of worthless and un-

wholesome territory in the vicinity of Hill's Crossing was readily and successfully reclaimed.

For this purpose a broad new channel, 10 feet wide and 4 feet deep, was constructed from the point where Wellington Brook enters Little River to the Belmont line, a distance of half a mile. This has so thoroughly drained the immediate district that the water level has in some places sunk more than 40 inches. Farther up the stream in Belmont, lands which were under water last summer — one of the dryest seasons in many years — have been so thoroughly reclaimed that they are now dry and available for cultivation. The map and photographs will serve to show the extent and character of this work better than any merely verbal description could possibly do, and to them the reader is referred for detailed information.

The work which has already been done through the combined action of the Boards of Health of Cambridge and Belmont, has cost about $1,600, of which Cambridge's share was $1,100, and Belmont's, $500. No assessment upon any of the landholders has been made by either of the Boards, as it was held that these unsanitary conditions were brought about through natural causes, and that their removal was for the common good of the public at large.

While Belmont has no further cause of complaint in so far as her own lands are directly concerned, that town is nevertheless near enough to a portion of territory which still remains undrained to feel its evil effects. It is to be hoped that some method will soon be devised whereby the towns and cities chiefly concerned (Belmont, Arlington, Cambridge and Somerville) may coöperate and adopt some definite measures concerning the sanitary treatment of these lower marshes for their mutual benefit, and also for the benefit of the public at large, as the condition of these may materially affect the health of other near-by towns.

There is still much to be done before some of the neighboring territory can be brought into a healthful and useful state. To accomplish this the coöperation of Arlington, Somerville and Cambridge with Belmont is indispensable. The placing of tide-gates at the mouth of Alewife Brook where it empties into Mystic River would remedy existing evils at comparatively small expense. This whole neighborhood possesses many natural beauties, and if developed, could be made wholesome and attractive, instead of what it now is, an unsightly area of waste and swampy lands, and a menace to the public health.

A map of the Fresh Pond marshes and some of the contiguous territory has been prepared under the author's direction and is shown above. The boundaries of the cities and towns immediately concerned are clearly indicated, as are also the course of Wellington Brook, Alewife Brook, and the location of the Mystic River, as well as of the new channel which has already proved so effective.

Photographs made by the author illustrating what has been done, as well as the need of still further improvements in the lower part of the territory under consideration, are appended. The legend under each will suffice for its explanation. The points where the photographs, Figures 1, 2, 3, etc., were taken, are indicated on the map by corresponding numerals enclosed in circles, and in several cases small arrows adjoining the circles show the direction in which the camera was pointed.

NOTE ON DRAINAGE AND MOSQUITOES.

"After all, the best of the means which may be adopted against mosquitoes will always consist in the abolition of their breeding places. Small pools with stagnant water can be 'treated,' but it is a great deal better to drain them or to fill them up. Swamp areas must sooner or later be drained. It is perfectly obvious that the sooner this is done the better from every point of view, not only from that of human health, but from the increased value of real estate in the neighborhood, and from the practical value of the reclaimed land itself. The time is coming, and rapidly, when this drainage of large swamps will not remain a matter which concerns the individual owner of the land, but one for town or county action, and even for States. The report of T. J. Gardner on the policy of the State respecting drainage of large swamps, published in the Report of the Board of Health for New York, Albany, 1885, although antedating the recent important mosquito discoveries, is well worth reading by all public-minded persons, and the annual reports of the State Geologist of New Jersey, for 1897 and 1898, in which the reclamation of the great Hackensack Meadows, near Jersey City, Newark, and Elizabeth, New Jersey, make interesting reading along this line. Work on these marshes has actually been begun. The solution of this case is taking the form of separate action by cities and their municipalities, each improving the territory within its corporate limits. The city of Newark has a tract of 4,600 acres of marsh within its limits. Jersey City has within its limits 2,086 acres of tide-marsh,

and Elizabeth has 2,658 acres. The three cities, therefore, have about 8,700 acres of the 27,000 acres lying between Elizabeth and Hackensack. The sanitary importance of reclaiming these lands is of the greatest, but the capabilities of the improvement plans are also attracting attention on the part of capitalists and business men, who see in these tide-lands valuable sites for manufacturing, industrial, and commercial activity." — *Professor L. O. Howard, Entomologist, United States Department of Agriculture.* "Notes on the Mosquitoes of the United States," p. 63. Washington, 1900.

TECHNOLOGY QUARTERLY

AND

PROCEEDINGS OF THE SOCIETY OF ARTS.

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PROCEEDINGS OF THE SOCIETY OF ARTS.

THIRTY-NINTH YEAR, 1900–1901.

BOSTON, January 24, 1901.

THE 547th regular meeting of the SOCIETY OF ARTS was held on this day at the Institute, Rogers Building, at 8 P.M., Professor Swain presiding. Forty-five persons were present.

The following were elected to Associate Membership: P. Schuyler Miller, Assistant Chemist, Department of Water Supply, Brooklyn; William C. Ewing, Civil Engineer; Henry R. Batcheller, Mining Engineer. The records of the previous meeting were read and approved.

Mr. William H. Lincoln, President of the Boston Chamber of Commerce, was introduced and gave a most interesting and comprehensive talk on "Shipment of Freights to Europe." The diminution in the rate of freights, and the change in the methods of transportation from sailing vessels to immense freighters, have enabled the United States to compete with the world in commercial enterprises. Last year the balance of trade was over $600,000,000 in our favor, almost wholly with Europe, and chiefly with Great Britain. England purchases over $400,000,000 more in supplies from the United States than we import from her.

Since the invention of the ammonia process of refrigeration, the exportation of fresh meats to England has increased enormously, re-

sulting in the lowering of the price of meat in England to one-half. Likewise the shipment of live stock has increased. The industry was started in 1875 and carried on for several years at a loss. Often the entire cargo would be swept away during a storm, or die of exposure. At present the methods of transportation have become so perfected, that last year the Leyland Line carried 30,000 head of cattle with a loss of only 18.

Of the world's crops, the United States produces: 80 per cent. cotton; 80 per cent. corn; 30 per cent. provisions; 25 per cent. wheat; 80 per cent. iron; 33 per cent. coal; 40 per cent. steel. Our manufactured products exceed those of England, France and Germany combined. Mr. Lincoln's paper is published in the TECHNOLOGY QUARTERLY for March, 1901.

In the discussion which followed, Professor Swain referred to the manufacture of Portland Cement as an illustration of our ability to enter and successfully compete with well-established European industries. The thanks of the Society were extended to Mr. Lincoln for his instructive address.

BOSTON, January 31, 1901.

A special meeting of the SOCIETY OF ARTS was held on this day at the Institute, Rogers Building, Professor Cross presiding. One hundred and seventy-five persons were present. The report of the previous meeting was read and approved.

Professor George E. Hale, Director of the Yerkes Observatory, spoke on "Astronomical Photography with the great Visual Telescope of the Yerkes Observatory." This telescope, which has a 40-inch objective and 64-foot tube, is the largest refracting telescope in the world. Though constructed for visual observation, Professor Hale has succeeded in using it for photographic work, obtaining results due to its tremendous resolving power.

Owing to this power of separation, the hearts of star clusters have been resolved into thousands of stars, and details of the moon obtained, surpassing all previous work with telescopes especially designed for photographic work. Spectroscopic attachments to the telescope have enabled the constitution of stars and their life history to be carefully studied, likewise the velocity of stars in the line of sight, and of gas eruptions on the sun's surface.

The spectroheliograph, devised by Professor Hale, permits the study of the sun's surface with one color of the spectrum to the exclusion of all others, a method which has already led to important results concerning the sun's surface. Indeed, a large field for research was mentioned as open to the astronomer, using large visual telescopes as photographic ones.

It is to be observed, however, that the objectives of visual telescopes are constructed of glass which is transparent to waves capable of stimulating the sensations of light, but not to exceedingly short ones. Consequently such visual telescopes cannot be used in the photographic study of the invisible portions of the spectrum.

The thanks of the Society were most heartily extended to Professor Hale for his able, clear and very instructive lecture.

BOSTON, February 14, 1901.

The 548th regular meeting of the SOCIETY OF ARTS was held on this day at the Institute, Rogers Building, at 8 P.M., Professor Chandler presiding. Two hundred persons were present. After the regular business had been transacted, Mr. Robert S. Peabody, President of the American Institute of Architects, spoke on "The Designing of the Buffalo Exposition."

A most interesting account was given of the method followed by the eight prominent architects who were chosen to design the Exposition grounds and buildings. Each member of the committee was requested to present a sketch which should embody his ideas regarding the most suitable and artistic plan for an Exposition. At the first meeting of the committee, these plans were carefully discussed, the remarks being recorded by stenographers. After the meeting, each member was presented with a copy of these criticisms and suggestions, and requested to present a new scheme at the second meeting. In this way a satisfactory plan for the Exposition was obtained. The same method of frank criticism was followed in the designing of the buildings, over twenty in number. Some of the latter are to form permanent additions to the city of Buffalo, such as the New York State Building, afterwards to become the home of the Buffalo Historical Society and the Art Museum.

The present Exposition will differ from the Chicago Exposition in many ways. The buildings will be constructed with projecting eaves,

with large tiled roofs, and will be decorated in the most intense colors. Sculpture will be used in profusion for decorative purposes. Many views were shown of the original sketches, the buildings which are already near completion, and groups of statuary.

The selection of Buffalo as the seat of the Pan-American Exposition seems to have been an excellent one, owing to its nearness to Niagara Falls, also to the fact that over 40,000,000 people reside within one night's ride of the city.

The thanks of the Society were extended to Mr. Peabody by Professor Chandler.

BOSTON, February 28, 1901.

The 549th regular meeting of the SOCIETY OF ARTS was held on this day at the Institute, at 8 P.M., in Room 22, Walker Building, Professor William H. Niles presiding. Two hundred and sixty persons were present. After the regular business had been transacted, Mr. Gifford Pinchot, Chief of the Division of Forestry, Washington, D. C., was introduced and spoke on "A Forest Policy for the United States."

The speaker introduced the subject by showing a map of the Forest belts which cover about 37 per cent. of the territory of the United States, after which slides were shown and explained illustrating the character of the timber growth of these belts, likewise the effect of forest fires, and the ruinous policy which is being pursued by the miners and farmers in the South and West. In some mining districts wood is used extensively as fuel, owing to the great expense of coal, without any adequate provision being made to replace the same. Moreover, in the South and West large tracts of excellent timber are destroyed to be converted into very poor farming land. The speaker referred to the influence of forests upon climatic conditions, and especially emphasized the dependence of the 200 millions acres of land devoted to agriculture in Oregon for its water supply upon the preservation of the forests in that state.

The latter part of the lecture was devoted to a consideration of the features which must dominate any forest policy adopted by the United States Government. The methods successfully followed in Germany are impracticable in this country, owing to the difference in the customs and habits of the people. With us, moreover, the lumber industry is

an exceedingly important one, the amount of lumber used per head being greater than anywhere else in the world. Consequently any governmental policy must preserve the forests, and at the same time consider these rights and interests. In this country, also, great damage results from forest fires, which are seldom known in Germany. Experience has shown that the following factors should be considered in the framing of any forest policy for the United States:

1. Geography of the timber belt.
2. National habits of mind.
3. Grazing interest.
4. Fires.
5. Large lumber interests.
6. Relation of forests to water supply.
7. The tax rate on timber land. This should never be so high as to prevent the owner from holding the land for timber.
8. A Bureau should be established in Washington to which persons could come or write for advice and information.
9. There should be a body of young men trained in forestry to take charge of a forest policy and put it into successful operation.

At the close of the lecture remarks were made by Mr. Egerton, recent Chief of the Division of Forestry; Mr. Harvey N. Shepard, Chairman of the Board of Trustees of the Appalachian Mountain Club Real Estate; and Professor Fay, of Tufts College.

The thanks of the Society were extended to Mr. Pinchot for his most interesting and instructive lecture.

BOSTON, March 14, 1901.

The 550th regular meeting of the SOCIETY OF ARTS was held on this day at the Institute, at 8 P.M., Mr. George W. Blodgett presiding. Ninety-five persons were present. After the regular business had been transacted, Dr. Henry Fay, Assistant Professor of Metallography at the Institute, was introduced and spoke on "The Use of the Microscope in the Study of the Chemical Constitution and Physical Properties of Metals." The need of some method of investigation for distinguishing between steels of the same composition, but of different physical properties, led to a microscopic study of the structure. The foundations of this microscopic analysis were laid by Sarby, and

extended by Martens, Osmond, Roberts-Austin, Stead, Sauveur and others.

It was found that an exact analogy existed between solutions and alloys — steel itself acting as an alloy. This analogy is most advantageously shown, 1st, by a study of the fusibility curves; 2d, by examination of polished and etched sections with the microscope.

The fusibility curves of alloys have been found to fall under three general classes:

I. Two metals which form solid solutions give a straight-line curve connecting the two melting-points. Examples of this class are the alloys of silver and gold, and bismuth and antimony.

II. Two metals which neither form solid solutions nor compounds, give a two-branch curve, meeting in an eutectic point, which is lower than the melting-point of either metal. Typical examples of this class are the alloys of tin with bismuth, lead, and zinc, and the alloys of zinc with aluminum and cadmium.

III. Two metals which form one or more compounds give a curve, the number of branches of which is $2n + 1$ where n represents the number of compounds. In this class one of the compounds may form a solid solution with one of the pure metals, which would, consequently, modify the character of the curve, and therefore change the number of branches. Examples of this class are the alloys of copper with antimony, tin, and bismuth; those of aluminum and gold, antimony and zinc, and tin and nickel.

The study of the microstructure of these three classes of alloys confirms very decisively the fusibility curves. In the first class it is known that the solvent and dissolved substance separate out together. The microstructure of metals which form solid solutions shows a homogeneous mass in which it is difficult, if not impossible, to distinguish between the two constituents. In the second class, where the freezing-point of the pure metal is considerably lowered by the addition of the other metal, there is first a separation of pure solvent, and as the temperature of the solution is lowered, the pure metal continues to separate until the concentration of the resulting solution has reached that of the eutectic alloy, when the mass solidifies as a whole. The microscopic constituents, consequently, should be pure metal and the eutectic, the amount of each depending upon the proportion of the two constituents. As the eutectic is the alloy in which the two constituents are each saturated with the other and the two separate simultaneously, we

find a structure made up of alternate layers of the two metals. The structure for all eutectics is very characteristic, resembling the fine line markings of the thumb. The eutectic may consist of two metals, a metal and a compound, or two compounds, but in all cases its structure is characteristic. The presence of compounds in the third class is usually recognized by their crystalline form, the forms of some of them being very characteristic, such as is the case for the compound $SnCu_3$. When, however, a compound forms a solid solution, the detection of the two constituents is much more difficult.

The microstructure of alloys was illustrated by photographs of lead-tellurium alloys.

Steel was considered as an alloy of iron and carbide of iron, and was shown to belong to the second class of alloys. The microstructure of steels subjected to various heat treatment was illustrated by photomicrographs.

The thanks of the Society were extended to Dr. Fay for his instructive address.

BOSTON, March 28, 1901.

The 551st regular meeting of the SOCIETY OF ARTS was held on this day at the Institute, at 8 P.M., in Room 22, Walker Building, President Pritchett presiding. Over three hundred and fifty persons were present. The following persons were elected to Associate Membership: Mr. F. F. Low, 101 Milk Street, Boston; Mr. R. G. Hall, Pueblo, Colorado; Professor C. E. Fuller, Massachusetts Institute of Technology; Dr. F. J. Moore, Massachusetts Institute of Technology; Mr. R. R. Laurence, Massachusetts Institute of Technology; Mr. C. W. Berry, Massachusetts Institute of Technology; Mr. C. H. Hapgood, Massachusetts Institute of Technology.

Dr. M. I. Pupin, Professor of Electro-Mechanics at Columbia University, spoke on "Electrical Wave-Transmission." Experiments on the propagation of waves over cords were shown. A résumé of the lecture will be found below, pages 89–91.

The thanks of the Society were most heartily extended to the speaker for his interesting, instructive, and clear presentation of the subject.

GEORGE V. WENDELL, *Secretary.*

TESTS OF THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY TAPE APPARATUS.

By ALFRED E. BURTON, S.B., Professor of Topographical Engineering, Massachusetts Institute of Technology,

AND

JOHN F. HAYFORD, C.E., Inspector of Geodetic Work, United States Coast and Geodetic Survey.

Introductory Note.

Alfred E. Burton.

The so-called "Massachusetts Institute of Technology Tape Apparatus," is an indirect product of the Summer Schools of the Civil Engineering Department. As early as 1888, at the Summer School held at South Deerfield, Massachusetts, a base line was measured with the suspended steel tape. During this and the following two years, the apparatus used was similar to that employed by the Missouri River Commission in 1885, slightly modified to increase the speed of measurement. In 1891, Mr. Harry C. Bradley and Mr. George A. Campbell took for their thesis the subject of base measuring with the steel tape. To Mr. Bradley is due the design of an automatic stretching device which makes it easy to secure a uniform tension, the value of which can be determined to a fraction of an ounce. Mr. Campbell designed an apparatus to determine the coefficients of expansion of tapes in air. He also suggested and discussed the method of determining the expansion of the tape by a measurement of its electrical resistance. In 1892, Mr. William C. Thalheimer in his thesis continued the work on the coefficients of expansion of steel and brass tapes begun by Mr. Campbell. In 1892, measurements were made with the steel and brass tapes, using their relative coefficients of expansion, for the determination of the temperatures. That year, several measurements were made at night, and in this work the actual differences between measurements did not exceed one part in

a million. At the Summer School held at Keesville, New York, in 1893, Mr. Campbell took direct charge of the base measurements in order to test, in the field, the method of determining electrically the expansion of the tape due to temperature changes. The degree of precision obtained was highly satisfactory, but the field work was slow, for the Wheatstone Bridge employed was not adapted for rapid work. The necessary modifications could not be attempted at the time, but were later found embodied in a form of Wheatstone Bridge for temperature measurements, invented by two of the Institute graduates.

In 1895 a paper[1] was read before the SOCIETY OF ARTS by Mr. George C. Whipple, graduate of the class of 1889, describing "The Thermophone" recently invented by Henry E. Warren, '94, and himself. At this time it occurred to the writer that here was an instrument for solving in the simplest manner the long-vexed problem of the determination of the temperature of a steel tape when used in base measuring. The thermophone, with slight modifications, could be made to do the work expeditiously and satisfactorily. Messrs. Warren and Whipple entered into the scheme gladly, and both lent their aid towards the final solution. Mr. Warren in the Summer School of 1896, held at Machias, Maine, took direct charge of the base measurements and obtained results that surpassed the most sanguine expectations. Meanwhile, in 1895, Messrs. Francis E. Matthes and Gerard H. Matthes had taken up steel tape measurements as a thesis, and they undertook and carried through in a most satisfactory manner the calibration of a thermophone for the 100-meter steel tape, and the 100-meter German silver wire. The thermophone, as completed by these students, reads directly the mean temperature of the tape to a tenth of a degree Fahrenheit.

The above account gives a brief history of this tape apparatus up to the time the test was made by the United States Coast and Geodetic Survey, in November, 1900. In this test many of the minor appliances that had been used to further increase the accuracy of measurements were left out, the officers of the Coast Survey considering that we were needlessly increasing the refinement of measurement and thus decreasing the speed of work. The measurements at the Summer School have always shown a smaller probable error than was brought out by the test.

[1] See *Technology Quarterly*, July, 1895.

It appears to the writer that in this evolution of a base measuring apparatus there is an interesting example of thesis work which has tended to develop the faculty for original research.

A number of students' names have been mentioned as directly concerned in the development of this apparatus, but it would only be fair to say that valuable suggestions have been from time to time received from other students, and from several of the instructors at the Summer Schools.

Tests of the Massachusetts Institute of Technology Tape Apparatus, Made by The Coast and Geodetic Survey in November and December, 1900.

John F. Hayford.

The object of these tests of the Massachusetts Institute of Technology tape apparatus was to determine its adaptability to the measurement of primary bases by the Coast and Geodetic Survey. In considering these tests it should be kept clearly in mind that results of the extremely high degree of accuracy which are stated to have been obtained with this apparatus are unnecessary in connection with primary triangulation. The base measurement is ordinarily the strongest part of the work, and very little accuracy is gained by reducing the probable error of a base further after a probable error of one part in 500,000 has been obtained. In making the tests it was continually kept in mind that what was wanted was a method of measurement which should be as rapid as possible while securing a probable error not exceeding one part in 500,000.

Two full days were devoted to the tests in November at Washington, and three afternoons on the Alice Base Line in southern Texas in December.

The tests made at Washington consisted of repeated readings on a single tape length between fixed points, the tape being supported at intervals of 25 meters on nails or a wooden arm. One end of the tape was fixed rigidly, and the readings taken at the other end. No glass rollers were used to relieve the friction at the reading end. The conditions differed from those ordinarily encountered in the measurements by students at the Massachusetts Institute of Technology, in that the support interval was changed from 10 to 25 meters; that there was considerably more friction at the fixed nails or other

supports than with the swinging hook supports ordinarily used; and that a little extra friction was encountered at the reading end. The conditions as stated were similar to those which are allowed to exist with the 50- and 100-meter tapes actually in use during this season in the Coast and Geodetic Survey base measurement, and it was believed that the desired accuracy, namely, a probable error of one part in a half million, could be obtained under these conditions. On November 13, ninety readings of a single tape length were taken between 10.24 A.M. and 8.54 P.M., and on November 19, seventy readings between 10.10 A.M. and 7.51 P.M., by Mr. L. A. Fischer, Adjuster, United States Office of Standard Weights and Measures, and the writer. On each day the temperature conditions varied greatly, part of the measurements being made in bright sunlight, a part with one portion of the tape in sunlight and another in shade, other measurements being made during daylight but with the sun under a cloud, and the latest measurements on each day being considerably after sunset. The measurements all being reduced to a fixed temperature, using the known coefficient of expansion of the tape, showed a total range of 2.3 millimeters on the first day, and 2.6 millimeters on the second. On taking the sums of the measurements in successive groups of ten, corresponding to measurements of 1 kilometer each, the total range was 8 millimeters on the first day, and 7 millimeters on the second. These ranges are no greater than are obtained in the regular base work of the Survey which serves to give a probable error of one part in a million or less on each base, and therefore indicate that even under these conditions the tape gave sufficiently accurate results for the required purpose.

On December 10, on the Alice Base Line, Professor A. E. Burton and the writer spent the afternoon in making measurements of a single tape length, the tape being supported upon tripods. This afternoon's work was of little value except as preparation for the later tests. Similarly, on December 13, 1 kilometer of the base was measured once with the aid of the base party under Mr. A. L. Baldwin, and served mainly to give the party practice with the apparatus. On December 17 a section of the base nominally $\frac{1}{2}$ kilometer long was measured six times with the aid of the base party, two or more readings of the tape and thermophone being taken in each position. During these measurements instrument tripods, modified slightly to adapt them to the purpose, were used as marking points for the ends

of the tape, and the middle point of the tape was supported on one of the tripods ordinarily used with the base bars. The tape, therefore, hung in two catenaries, each 50 meters long. At the middle support the tape rested across a heavy metallic roller which ordinarily supports one end of a base bar. This roller served to relieve the friction to a small extent, but was, doubtless, less effective for that purpose than the swinging hook. The tension was applied with the Massachusetts Institute of Technology tension apparatus, and was 7.38 kilograms. The results of the measurements cannot be given in absolute units as, at the date of writing, the length of this section of the base has not yet been computed by the base party. The residuals from the mean of the six measures were, however, + 2.40 millimeters, — 3.12 millimeters, — .82 millimeter, + .37 millimeter, — .64 millimeter, + 1.84 millimeters.

During the first two measurements no friction rollers were used at the reading end of the tape. During the remaining four measurements a small roller was used for that purpose, and the residuals show clearly the increased accuracy gained thereby.

A study of the results, and especially of the readings taken in quick succession with the tape in a given position, indicates that while with the 50-meter interval between supports the required degree of accuracy could probably be obtained during perfectly still weather, the effect of the wind upon the apparent length of the tape is so great that under ordinary conditions this interval is too great for safety. The total time required to make these six measurements of the half-kilometer section was 250 minutes, or 83 minutes per kilometer, in spite of various delays due in part to inexperience with this apparatus, and in part to defects in the apparatus itself which may easily be remedied.

A mere statement of the numerical results of the tests as given above indicates but poorly the information furnished by them. During the tests as careful studies as possible were made of the detail of the method and the apparatus. The results of these studies can be most conveniently stated in a readable form as an opinion upon the apparatus as a whole.

The three principal advantages of the thermophone method of determining the temperature of the tape are:

1. That the thermophone gives a determination of the actual temperature of the tape, regardless of whether the heat reaches the tape

in the radiant form or otherwise; whereas the ordinary mercurial thermometer receives at its bulb less radiant heat than a steel tape exposed under the same conditions, and, therefore, indicates too low a temperature when used in daylight. Attempts to get rid of this error by blackening the bulb of the thermometer or sheathing it with metal have proved unsuccessful, and it has, therefore, been absolutely necessary up to the present time to use steel tapes at night only when results of a sufficient degree of accuracy for geodetic purposes were required.

2. The thermophone furnishes an instantaneous determination of the temperature of the tape, whereas the mercurial thermometer responds much more slowly to changes of temperature than the tape, and therefore gives indications which are considerably in error at any instant whenever rapid and irregular fluctuations of temperature are in progress.

3. The thermophone furnishes a measurement of the actual mean temperature of the whole length of the tape, whereas with mercurial thermometers all that can be hoped for under the best possible conditions is a determination of the tape temperature at two, three, or more points at which thermometers are placed.

In regard to the Massachusetts Institute of Technology Tape Apparatus as a whole, the writer is convinced:

1. That with the thermophone apparatus in its present form, and using all refinements, measurements can be made, even in daylight and when the temperatures are varying rapidly, with a much higher degree of accuracy than is possible with tapes and mercurial thermometers even under good conditions at night.

2. That after the apparatus has been modified and strengthened at certain points with reference to making it proof against comparatively rough usage and capable of quicker manipulation, certain refinements being omitted, much more rapid measurements can be made with it than with any form of bars, and probably more rapid than with the present form of tape apparatus, if the tripod method rather than the stake method is used.

3. That it can be used efficiently with no more previous preparation of the ground than is necessary for bar measurement by substituting tripods for the marking stakes at the tape ends and for the intermediate supports.

Base measurements with bars have ordinarily been made with the

bars supported upon portable tripods. It has not been feasible to measure primary bases with tapes similarly supported upon tripods, since it was absolutely necessary to make the measurements at night to secure the necessary degree of accuracy with the means heretofore available for determining the temperature. The thermophone apparatus determines the temperature with all necessary accuracy in daylight. Hence, it is now possible to substitute tripods, or other portable supports, which may be placed in position as the measurement progresses, for the fixed stakes which have heretofore been used. With a well organized base party familiar with the work, the setting of the stakes requires considerably more time than the subsequent double tape measurement of the base. For example, the base party which has just finished its operations, found it possible to make two measurements of each kilometer of the base in from 1 to $1\frac{2}{10}$ hours upon an average, whereas the setting of the stakes on a single kilometer required $2\frac{1}{2}$ to 3 hours, six or eight men being required for the tape measurement, and four for the stake setting. If the Massachusetts Institute of Technology Tape Apparatus is used upon stakes, no time can be saved in the measurement, and the only thing that will be gained by substituting it for the tape apparatus at present in use in the Survey, using mercurial thermometers, is that the measurements may be made in daylight, instead of at night. If tripods are substituted for stakes, however, the only previous preparation of the ground other than clearing it, is a very rough preliminary measurement made with a tape dragged upon the ground, requiring, say, 45 minutes per kilometer for a party of three men; and this rough measurement is necessary even when bars are used. It is to the Massachusetts Institute of Technology Tape Apparatus used upon tripods or other temporary supports, rather than upon stakes, that one must look for gain in time over the tape methods now in use in this Survey.

In closing, it may be noted that the attempt to substitute a 50-meter support interval for the 25-meter interval now in use was made because such a change, if feasible, would be conducive to very rapid work with a tripod method, the number of necessary supports being greatly reduced.

ELECTRICAL WAVE-TRANSMISSION.

By MICHAEL I. PUPIN, Ph.D.

Read March 28, 1901.

Electrical wave-transmission over a wire conductor has a mechanical analogy in wave-transmission over flexible cords. The application of a force to one end of a cord develops three reactions: mass, tensional, and frictional reactions. The energy used up in overcoming the first two is non-dissipative, *i.e.*, it is stored up in the cord along which it is propagated; whereas, the energy consumed against frictional reaction is wasted as heat. Consequently, if there be sufficient frictional resistance, the wave will not extend far from the point at which the impressed force is applied before the energy imparted to the cord (as kinetic and tensional energy) becomes dissipated as heat. In the case of wave-transmission along a cord, it is this dissipative factor which causes the wave attenuation.

Similarly, when an alternating electromotive force acts on an electric circuit, the energy imparted to the wire conductor encounters three reactions: *inductance* reaction, which is the same in form as the kinetic reaction of a vibrating cord and is non-dissipative, its work being stored up in the system as magnetic energy; *capacity* reaction, the law of action of which is identical with the law governing the tensional reaction in strings, likewise non-dissipative; *resistance* reaction, in the overcoming of which heat is generated, therefore it is dissipative. Consequently in electrical wave-transmission, the energy is continually dissipated as heat on account of the resistance reaction and causes the attenuation which limits telephony over long conductors, particularly over cables.

Evidently, to diminish the attenuation in either of the above cases the non-dissipative factor must be made larger in comparison with the dissipative or frictional reaction, since a relatively smaller dissipation of energy would result. The conclusion is that the transmission over cords must be better through a dense medium, or cord, since the mass-reaction is thereby increased.

To illustrate this point, a light cord lying on an inclined rough surface may be set into periodic vibration at one end by a suitable mechanism. Owing to friction, the wave energy on the cord is propagated only a short distance, the attenuation being very marked. On increasing the tension and thereby increasing the tensional reaction, the wave progresses much further. By substituting a cord of larger mass, the distance of the wave propagation may be noticeably increased. With a given cord, if the tension has been increased as far as possible, what may be done to diminish the attenuation? Assuming that a heavier cord cannot be substituted, the effect of a cord of large mass may be secured by loading the cord with sinkers of metal at periodically recurring points. Certain experiments demonstrate clearly and beautifully, that the transmission can be much improved in this manner, provided the sinkers are suitably arranged.

The following conclusions were drawn from the above experiments: (1) It is more efficient to transmit energy over a heavy than a light cord. (2) A cord, if periodically loaded, may be made equivalent within any degree of approximation, to a heavier uniform cord. It is to be observed that the distance between consecutive loads must be smaller than the length of the wave which is transmitted.

Similar experiments suggested to the author, in the earlier stages of the research, the manner of attacking the electric problem. In any circuit the magnetic inductance (a source of non-dissipative reaction) is limited. It is well known that coils of wire possess large inductance, consequently such coils should act for an electric circuit in the same way that sinkers do for a cord, and the problem of electrical wave-transmission should reduce itself to the placing of inductance coils at proper periodically recurring points on the wire.

In order that such a non-uniform, or loaded, conductor may act as a uniform conductor of large inductance, it is necessary from mathematical analysis to distribute the loads at periodic distances which are small in comparison with the length of wave which is being propagated.

Since electrical waves in telephony are many miles long, it was impossible to carry out investigations on an actual line. An artificial cable, equivalent to 250 miles of line, was arranged in the laboratory at Columbia University, and inductances were placed at periodically recurring points. The current was measured and the waves plotted for the 250 miles. Using several frequencies the results of measurements were compared with the mathematical theory, and were in splendid agreement.

The practical value of this discovery is: (1) That wave-energy for telephony and telegraphy may be transferred over much greater distance. (2) If the distance remain constant, it enables wires of smaller size to be used, thus decreasing the cost of installation. (3) With the same weight of wire as in use at present, the distance of transmission may be greatly increased.

In the Atlantic cable, owing to the small magnetic reaction, and also small capacity reaction, the resistance reaction predominates by far, and the dissipation of energy is therefore enormous. By a proper distribution of inductance coils at periodically recurring points, say $\frac{1}{8}$ of a mile apart, the inductance reaction can be made very much larger than the resistance reaction for all frequencies which are of importance in telephony, and thus the dissipation diminished to any desired limit. The discovery may, and it is confidently expected that it will, result in the telephonic transmission across the Atlantic.

CONTRIBUTIONS FROM THE LABORATORY OF SANITARY CHEMISTRY.

II.

AIR TESTING FOR ENGINEERS.

BY A. G. WOODMAN AND ELLEN H. RICHARDS.

THE increased amount of carbon dioxide above the normal is usually relied upon as an indication of the extent of vitiation of atmospheric air. Hence sanitary engineers, architects, and building inspectors who have occasion to test the efficiency of ventilating systems for private and public buildings, schoolhouses, and halls, are often required to make numerous approximately quantitative determinations of atmospheric carbon dioxide.

For this purpose the usual laboratory methods for the exact estimation of carbon dioxide in the air are not suited. Such methods require the passage of a considerable volume of air for a long time through the absorbing solution, or else the collection of definite volumes of air for subsequent examination, and the use of carefully standardized solutions which must be preserved out of contact with the air and must be accurately measured. The analytical process demands a high degree of skill on the part of the operator, the value of the results obtained being in direct ratio to the care exercised in the collection and examination of the samples. For a comparatively small number of tests made in or near the laboratory where the highest degree of accuracy is desired, these methods are of great value, but for the demands of engineering practice, where in the course of a few hours from fifty to one hundred tests are to be made, and where comparative results rather than great accuracy are required, some simpler form of apparatus is desirable.

Such an apparatus, to be satisfactory, should meet, so far as possible, the following requirements:

(1) It should be sufficiently compact and portable to be carried in the hand from place to place, and should contain within itself everything required for the complete determination of the carbon dioxide.

(2) It should be as simple in construction as possible, and its use should not involve delicate measurements; if automatic in its action, so much the better.

(3) If possible, the apparatus should be made entirely of glass, avoiding prolonged contact of corks or of rubber connectors with any dilute solution which may be used.

(4) It should be so constructed as to protect the solution at all times from the carbon dioxide of the air, especially while the determination is being made, because of necessity such an apparatus must be used within the area of contamination.

(5) The complete apparatus should be sufficient for fifty or more determinations.

(6) It must be capable of giving results of a reasonable degree of accuracy, say within 0.5 part of carbon dioxide in 10,000 parts of air, in the hands of persons having little or no chemical knowledge and minimum skill in manipulation.

(7) If a solution be used in the apparatus it should be one which can be prepared easily from chemicals readily obtained; the solution must maintain its efficiency for a reasonable length of time, if protected from external influences; and the solution should be one which it is not at all dangerous or obnoxious to use.

Experience with several forms of simple apparatus which have been proposed has shown that none of them answers perfectly to the above requirements. Methods which were satisfactory a few years ago are no longer reliable. The question at present is not whether the air contains 15 or 20 parts of carbon dioxide per 10,000, but whether it contains 5 or 8.

Simplicity of apparatus is much to be desired, but it should not be gained at too great sacrifice of accuracy. Even when no greater precision is required than is necessary to meet the demands of practical work, it is out of the question to measure the test solution by means of an ordinary pipette or to preserve it for any length of time in stoppered vials; the strength of the solution is almost certain to be reduced by contamination with the breath, by contact with rubber or cork. In the directions given for the use of these simple forms of apparatus, not enough stress is laid upon the necessity for extreme care in the use of these very dilute solutions, the strict observance of conditions which might well be neglected in ordinary analytical procedures being here an essential factor of success.

Of the various simple methods which have been tried in this laboratory, perhaps the most generally satisfactory from the standpoint of the engineer is that proposed by Dr. G. W. Fitz, and next, the method of Cohen and Appleyard.[1] A brief description of these two methods in their original form may not be out of place here.

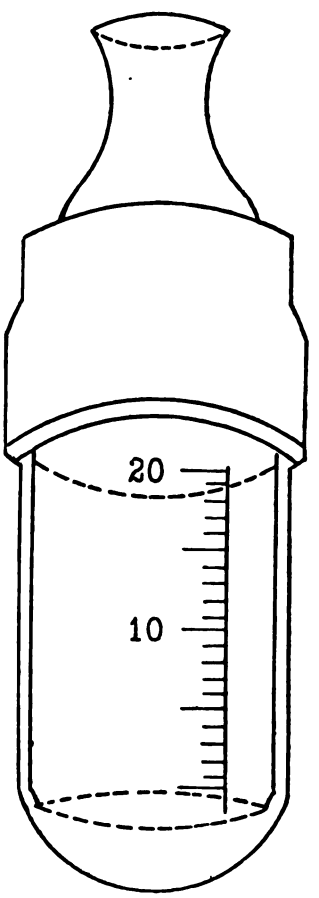

FIG. 1.—FITZ SHAKER. FULL SIZE.

The Fitz method is carried out by shaking a small quantity of dilute lime water, colored pink by phenolphthalein, with successive portions of air until the solution is decolorized. The greater the amount of carbon dioxide in the air, the less will be the volume of air required to neutralize the lime water, and *vice versa*. That is, the amount of lime water remaining constant, the amount of carbon dioxide will vary in a certain inverse ratio to the volume of air.

The solutions used are a 1 per cent. solution of phenolphthalein in alcohol, diluted with 4 parts of water, and a "saturated" solution of lime, made by shaking an excess of unslaked lime with water. The essential parts of the apparatus are several small homeopathic vials, holding about 10 cubic centimeters each, and a "shaker." This consists of a tube of about 30 cubic centimeters capacity, closed at one end, and graduated for a distance of 20 cubic centimeters from the closed end. In this tube by means of a rubber collar, slides a smaller tube which is contracted at the outer end so as to be more readily closed by the finger. The apparatus is shown full size in Figure 1.

Before making a test of the air, 10 cubic centimeters of dilute lime water, prepared by diluting the "saturated lime water" to one one-hundredth of its strength, is placed in each of the vials. When

[1] Chem. News, 70, (1894), 111.

ready to make the test this solution is poured from the vial into the shaker and shaken with successive portions of air until the color disappears. The first test will give the approximate amount of carbon dioxide, and succeeding tests, made by using the solutions in the other vials will aid in approaching the correct result. After thus determining the amount of air required to produce decolorization, reference is made to the table furnished with the apparatus, a copy of which is subjoined.

TABLE USED WITH THE FITZ APPARATUS.

Air in c.c. used.	CO_2 in 10,000.	Air in c.c. used.	CO_2 in 10,000.
30	28	91	9 Bad.
36	22	103	8
46	18	117	7 Fair.
58	14 Very Bad.	138	6
69	12	165	5 Good.
82	10	207	4

This apparatus is certainly sufficiently simple and portable, but a thorough trial of it has shown that it is open to several serious sources of error. One of these is in the preparation of the test solution. One cubic centimeter of "saturated lime water" is a rather small quantity to be measured accurately by unskilled persons, and there can hardly be any question concerning the danger of reducing the strength of the solution through repeated transfers of 10 cubic centimeters of it to the vials by means of an ordinary pipette. Further, the dilute solution must remain in contact with the rubber stopper of the vial until it is used, and while this may not be detrimental in all instances, cases are not infrequent in which the strength of the solution is so greatly diminished that the pink color nearly disappears in a day. In regard to the manner of using the shaker, the directions are decidedly vague upon a most important point. It is stated that the instrument is to be "shaken vigorously twenty-five or more times." A trial of the instrument in outdoor air will readily show that it makes considerable difference whether the apparatus be shaken twenty-five or *more* times. When testing air which is low in carbon dioxide, if the instrument be shaken only twenty-five times, the results will be much below the

solution weigh about 8 pounds. The case is furnished with a handle at the top so that it may be carried readily in the hand from place to place. The complete apparatus is shown in Figure 3. The bottle is fastened to the case, and the lower end of the pipette is clamped to a wooden support to keep it from swinging.

The bottle should be thoroughly cleaned and washed with potassium

FIG. 3. — THE COMPLETE APPARATUS.

bichromate and sulphuric acid, and it is best also to steam it for half an hour or so. As a further measure of precaution, the rubber stopper is boiled with dilute caustic potash and thoroughly washed, although the solution can come in contact with it only through splashing while the case is being carried.

The advantages of this arrangement will be obvious. The apparatus, while sufficiently light to be portable, contains sufficient solution for 90 to 100 tests. There is no danger of its being broken with

ordinary care in using it, and it is practically automatic in its action. The solution is protected perfectly from the carbon dioxide of the air and never comes in contact with anything but glass.

The method of preparation of the solutions and the manner of making the tests which have been found to give the best results will be described in detail, since experience has shown that these directions cannot be too minute.

Preparation of the Test Solution. — The solution used is a dilute solution of lime water colored with phenolphthalein. To freshly slaked lime add twenty times its weight of water in a bottle of such size that it is not more than two-thirds full. Shake the mixture continuously for 20 minutes, and then allow it to settle over night or until perfectly clear. The resulting solution is the stock lime solution, or "saturated lime water." If made in the manner indicated, each cubic centimeter of it ought to be very nearly equivalent to 1 milligram of carbon dioxide. If, however, it is desired to know the strength of it more exactly, it may be determined by standard acid.

To prepare the "test solution," pour into the 1-liter bottle of the testing apparatus 1 measured liter of distilled water, and add 5 c.c. of solution of phenolphthalein (made by dissolving 0.7 gram of phenolphthalein in 50 c.c. of alcohol and adding an equal volume of water). Stand the bottle on a sheet of white paper and add the "saturated lime water," drop by drop from a pipette, shaking the bottle thoroughly after each addition, until a faint pink color is produced which is permanent for 1 minute. Now add 12.6 c.c. of the "saturated lime water," shake, and immediately connect the bottle again to the apparatus.

To shorten the time required in testing air which is low in carbon dioxide, it may be found advantageous to use a solution only half as strong as the above. This "half solution" is prepared in precisely the same way, using 2.5 c.c. of the phenolphthalein solution, and 6.3 c.c. of the "saturated lime water."

While this procedure does not give an exact volume of solution, it is believed to be the best for the preparation of this dilute test solution, since it obviates the necessity for pouring the prepared solution from the measuring flask into the bottle in which it is kept; 12.6 c.c. of the stock lime solution is added rather than 10 c.c., in order to keep the values obtained with the resulting solution more nearly comparable with the older values calculated on the supposition that 10 c.c. of "saturated lime water" was equivalent to 12.6 milligrams of carbon dioxide.

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TABLE A.

Standard Test Solution. CO_2 in 10,000.	Cubic Cent. Air.	"Half Solution." CO_2 in 10,000.
22.2	50	15.6
18.0	70	12.4
15.1	90	10.2
13.0	110	8.7
11.3	130	7.5
9.9	150	6.6
8.8	170	5.8
8.0	190	5.2
7.3	210	4.8
6.8	230	4.5
6.3	250	4.3
5.9	270	4.1
5.6	290	3.95
5.4	310	3.8
5.1	330	3.7
4.8	350	3.6
4.7	370	...
4.5	390	...
4.4	410	...
4.2	450	...
4.0	490	...
3.9	530	...

Method of Making the Test. — See that the inner tube of the shaker slides readily in the outer one, moistening the rubber collar slightly if necessary. Have the inner tube pressed down to the bottom of the larger one, and measure into the apparatus 10 cubic centimeters of the test solution from the automatic pipette. Pull the inner tube up to the 5 c.c. mark (the bottom of the inner tube serving as the index) and close the end of the tube with the finger. Hold the apparatus horizontally, and shake it vigorously for exactly 30 seconds.

The amount of air which is thus brought in contact with the solu-

tion is equivalent to 30 cubic centimeters, as there are 25 cubic centimeters of air above the liquid when the small tube is forced to the bottom of the larger. Remove the finger, press down the small tube again to the bottom of the larger and draw it up to the 20 c.c. mark. Shake the apparatus again for 30 seconds. The amount of air brought in contact with the solution is now 30 + 20 = 50 c.c. Repeat the shaking, using 20 c.c. of fresh air each time, until the pink color is discharged. The amount of carbon dioxide corresponding to the number of cubic centimeters of air used will be found in Table A.

Notes and Precautions. — Care should be taken that the finger used to close the end of the tube is perfectly clean, since on a warm day the free acid in the perspiration might easily vitiate the results.

If greater accuracy is desired, the shaker should be filled with the air to be tested before running in the test solution. This may be done readily by filling the shaker with water and emptying it or by forcing air into the tube by means of a small rubber bulb.

The apparatus should be shaken vigorously and continuously during the 30 seconds in order to absorb practically all of the carbon dioxide in 20 c.c. of air. The number of shakings ought not to be less than 100 during this time.

Care should be taken not to contaminate the air while the sample is being taken. The breath should be held momentarily while the air in the apparatus is being replaced, and the sample should be collected as far to one side of the body as possible. It ought not to require over 10 seconds to replace the air, and the entire test, with air containing, say, 8 parts of carbon dioxide per 10,000, should not require over 6 minutes.

If less than 90 c.c. of air is required to discharge the pink color, the test should be repeated, using 10 c.c. of air each time after the first 30 c.c.

It is not necessary to rinse out the shaker after making each test, but it should be carefully washed and dried after using, and the parts kept separate when not in use.

The "half solution" is used in exactly the same manner and amount as the regular test solution, reference being made to the appropriate portion of the table.

For the Cohen method the same solutions may be used and measured from the same apparatus. The samples are collected in white, glass-stoppered bottles of 1-liter capacity. This may be done by aspirating the air with a bellows as directed in the original method, or the bottles may be completely filled with water which is then emptied at the place where the air is to be tested. Ten cubic centimeters of the

test solution are run in from the automatic pipette, the time noted, and the bottle shaken continuously and vigorously with both hands until the pink color vanishes. It will aid materially in determining the exact point of disappearance of the color if a piece of white paper, about $1\frac{1}{2}$ inches by 3 inches, is pasted on the side of the bottle near its lower edge, a similar piece joining it on the bottom of the bottle. In observing the color the solution is held in the angle formed by the pieces of paper and the disappearance of the color is more readily apparent. From the time required the amount of carbon dioxide in the air may be found by referring to Table B.

TABLE B.

CO_2 in 10,000. Standard Solution.	Time. Minutes and Seconds.	CO_2 in 10,000. "Half Solution."	CO_2 in 10,000. Standard Solution.	Time. Minutes and Seconds.
....	0.15	....	4.0	5.45
....	0 30	15.6	...	6.00
....	0.45	12.1	3.9	6 15
16.0	1.00	9.9	...	6.30
13.1	1.15	8.4	3.8	6.45
11.4	1.30	7.2	...	7.00
10.1	1.45	6.3	...	7.15
9.1	2.00	5.5	3.7	7.30
8.3	2 15	4.9	...	....
7.6	2.30	4.4	...	....
7.0	2.45	4.0	...	....
6 5	3.00	3.8	...	....
6 1	3.15	3.7	...	....
5.7	3.30	3.6	...	....
5.4	3.45	....	...	....
5.1	4.00	....	...	....
4.9	4.15	....	...	....
4.7	4.30	....	...	....
4.5	4 45	....	...	....
4.3	5.00	....	...	....
4.2	5.15	....	...	....
4.1	5.30	....	...	....

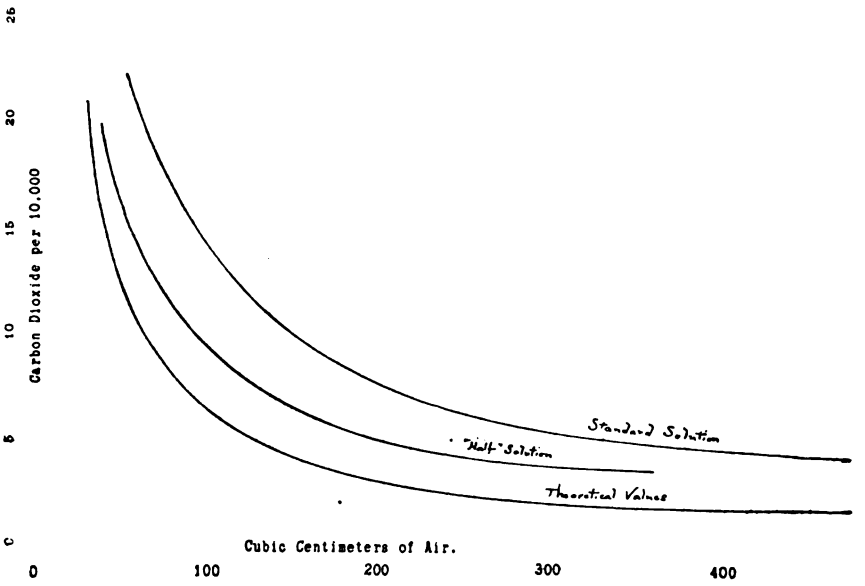

FIG. 4. — CURVES OF VALUES OBTAINED WITH FITZ SHAKER.

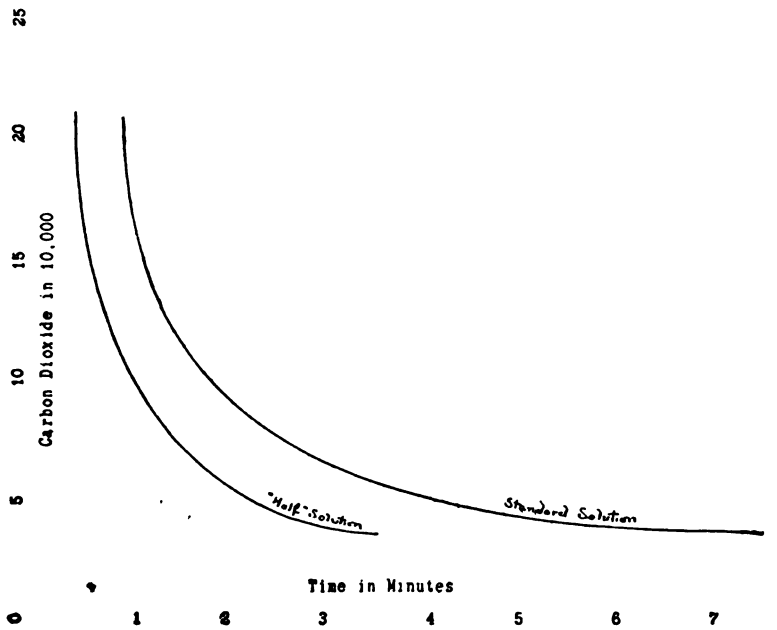

FIG. 5. — CURVES OF VALUES OBTAINED BY COHEN METHOD.

Having found by experiment the best mode of procedure in each case, a number of determinations have been carried out by both methods, using both the standard and "half solutions," in order to determine the correct values to be assigned in Tables A and B. Tests have been made exactly as just prescribed, in air containing varying amounts of carbon dioxide, the results being compared with samples taken at the same time, in which the exact amount of carbon dioxide was determined by the Pettenkofer method. The greater part of the tests were made in duplicate, and by two independent observers in order to eliminate the personal equation. Over 150 determinations were made by the Pettenkofer method, and many more by the others, the average results of a number of tests being taken as a basis for calculation. The samples below 10–12 parts of carbon dioxide were taken directly in rooms under normal conditions. For the samples showing more than this use was made of an air-tight chamber constructed for another purpose, in which the test could be carried out and samples taken for the Pettenkofer method simultaneously. When the air contained more than 15 parts of carbon dioxide, the test was made by using 10 c.c. of air each time instead of 20, as suggested above.

From the comparison of the results obtained, the curves have been plotted which are shown in Figures 4 and 5, each point plotted being the mean of a number of determinations. The values given in Tables A and B have been obtained by interpolation in these curves. It will be observed in Figure 4 that the values obtained by actual experiment are quite divergent in some parts of the curve, from the theoretical values, especially in the case of the lower values, the last traces of carbon dioxide being always much more difficult of absorption by dilute alkalies.

The automatic pipette was made for us in a most satisfactory manner by Emil Greiner, of New York. The Fitz "shakers" may be obtained from the L. E. Knott Apparatus Company, Boston.

MASSACHUSETTS INSTITUTE OF TECHNOLOGY,
Boston, Mass., March, 1901.

CONTRIBUTIONS FROM THE PHYSICAL LABORATORY OF THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY.

AN APPARATUS FOR RECORDING ALTERNATING CURRENT WAVES.[1]

BY FRANK A. LAWS.

THE apparatus forming the subject of this communication was constructed at the Rogers Laboratory in 1898, and has proved of sufficient value to merit a short description. In brief, the arrangement gives us a modification of the "contact method," by which the record is rendered continuous and traced photographically.

The necessary electrical connections are shown in the diagram, Figure 1. K_1 and K_2 are two rigidly connected contact wheels of ebonite. Into the periphery of each wheel are set four brass blocks. These are accurately placed 90° apart. Upon each wheel a brush and collector ring give permanent contact with the blocks. Another brush resting on the periphery of the wheel completes electrical connection as the blocks pass under it. The brushes are so placed that contact is made and broken at K_2 before K_1 closes. The contact wheels are driven by a synchronous motor, which gives one revolution for four complete alternations of the E. M. F. G is a dead-beat galvanometer, and C is an adjustable condenser. The leads a and b are carried to the points between which the P. D. is to be investigated. By inspection of the diagram it will be seen that once on each wave, and at a definite point the condenser C is charged to the potential existing between a and b. As the charge is determined by the breaking of the contact, the blocks may be of sufficient width to eliminate the effect of the jumping of the brushes. Also the resistance at the contact will not be of sufficient magnitude to prevent complete charging of the condenser.

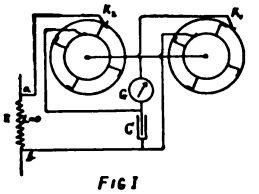

FIG 1

[1] Reprinted from the Proceedings of the American Academy of Arts and Sciences, Vol. 36, No. 17, January, 1901.

The function of K_1 is to discharge the condenser through the galvanometer after K_2 has broken circuit. The instrument would ordinarily experience a constant deflection, but K_1 and K_2 are rigidly connected and mounted on a radial arm, which is geared to the shaft so that it moves very slowly. The effect is to move gradually the contact point over the wave. The deflection of the galvanometer will at any instant be proportional to the P. D. between a and b at the instant of breaking at K_2, or in other words, the deflection follows the wave form.

The actual arrangement is shown in Figure 2 where the contact device, the synchronous motor, and the direct current motor used for starting the apparatus will be seen. By use of worm gearing the wheel

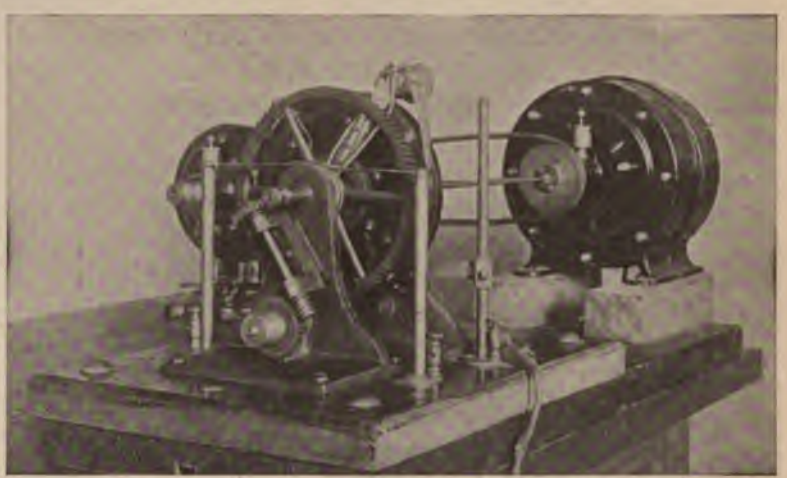

FIG. 2.—ARRANGEMENT OF THE APPARATUS.

train necessary for moving the brushes is made very compact; the reduction for the instrument shown is 7200 to 1.

I have found Sullivan's Universal Galvanometer to be a most satisfactory instrument for use with the apparatus. This galvanometer, of the D'Arsonval type, has a carefully balanced coil, so that it is not very susceptible to mechanical disturbances; also the magnetic damping is most carefully adjusted. The instrument is not of great sensitiveness, but owing to the stiff suspension the zero is perfectly definite.

The camera used for recording the curves is shown in Figure 3. The plate is contained in an ordinary plate holder. This is moved ver-

tically by a fine wire which is wound on a drum, seen in Figure 2, just in front of the lower worm-wheel. This drum can be thrown in at pleasure by a pin clutch. The slide of the plate holder is held stationary by a pin, so that the plate is exposed as the holder is drawn up.

The front of the camera, shown removed, is provided with a narrow slit about $\frac{1}{100}$ of an inch wide. In front of it are projecting lips 9 inches long and $\frac{1}{8}$ of an inch apart. They are blackened within, and serve effectually to shut out extraneous light, and thus prevent fogging of the

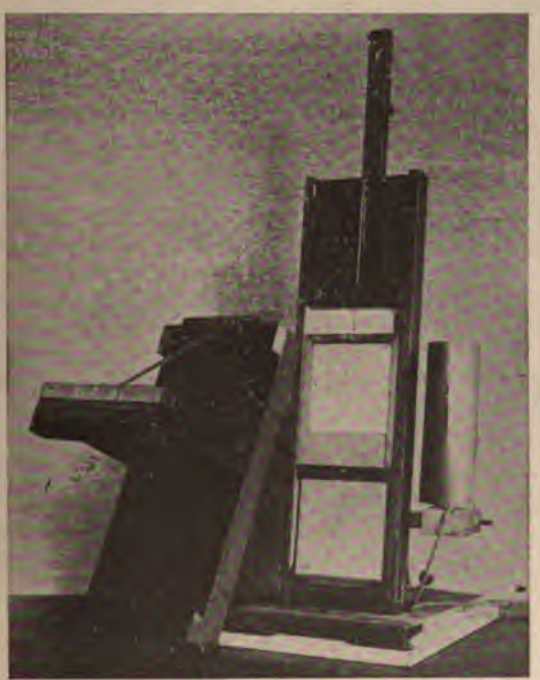

FIG. 3.—CAMERA FOR RECORDING THE CURVES.

plate The spot of light used was the sharply focussed image of the filament of an incandescent lamp. An alternative arrangement is to use a plate of ground glass in the holder, and to have a straight-edge fastened across the guides. It is then easy to keep the point of a pencil in contact with it and upon the spot of light.

The arrangement described is of course a device for obtaining the average wave, and unsuitable for recording transient phenomena. The time taken in recording a wave at 120 cycles per second is about $1\frac{1}{2}$ minutes.

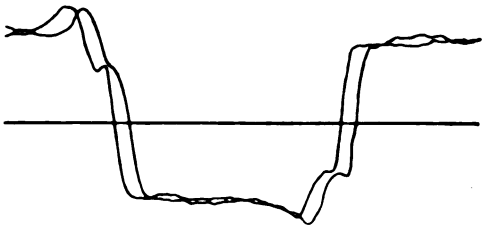

FIG. 4. — Potential difference between the carbons of an enclosed arc, in series with reactive coil.

The curves were taken about 1 minute apart with a view to testing the concordance of the readings.

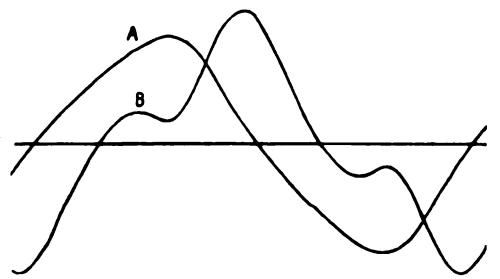

FIG. 5. — *A*, potential difference between the terminals of a small alternating current motor. *B*, current through motor.

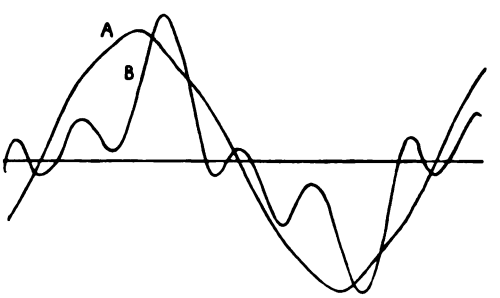

FIG. 6. — Curve *A* is E. M. F., and *B* is current in one phase of a quarter-phase synchronous motor running idle with the field adjusted for minimum current. Source of power was a three-phase dynamo with phasing transformers arranged on the Scott system.

The adjustable condenser allows one to adapt the apparatus to varying conditions, so the E. M. F. curves may be taken directly, and the current curves by the use of a drop wire, as indicated in Figure 1. In starting the arrangement it is very easy to determine when the proper speed for synchronism has been attained by watching the spot of light, or by listening to a telephone which is inserted in place of the galvanometer. With the latter one hears slow beats as the contact moves over the wave. On page 108 are given some examples of the records obtained with the device.

ROGERS LABORATORY OF PHYSICS,
June, 1900.

TYPHOID FEVER AT NEWPORT, R. I., IN 1900, AND ITS RELATION TO DEFECTIVE SANITATION.

By CHARLES-EDWARD AMORY WINSLOW, S.M.

The number of cases of typhoid fever reported to the sanitary officials of the city of Newport, Rhode Island, began to be excessive early in September of the year 1900. Week by week the disease spread, and about the middle of October the local authorities resolved to call in expert assistance. Specimens from certain sources of water-supply which had fallen under suspicion were sent to the Massachusetts Institute of Technology for examination, and were referred to Professor W. T. Sedgwick. At Professor Sedgwick's request, and under his general direction, I undertook the investigation of the outbreak, and I desire at the outset to express my thanks for his advice and assistance in its prosecution. I wish also to acknowledge the cordial coöperation of Dr. R. E. Darrah, of Newport, and of many other persons who aided me in the study of the conditions on the spot.

I. Prevalence of the Disease in Previous Years.

The amount of typhoid fever in Newport of late years has not been excessive as compared with that in other American cities. The records for the last five years are summarized in the following table, the reported cases having been obtained from the records of the Newport Health Office, and the deaths from the Registration Reports of the State of Rhode Island.[1] I have calculated the population for the years between the State Census of 1895 and the National Census of 1900, on a geometrical ratio.

[1] The figures for 1899 were obtained through the courtesy of Dr. Gardner T. Swarts, Registrar of Vital Statistics.

TABLE I.

TYPHOID FEVER IN NEWPORT, 1895–1899.

Year.	Population.	Reported cases of Typhoid Fever.	Deaths from Typhoid Fever.	Death rate per 100,000 population.
1895 . . .	21,537	32	9	41.8
1896 . . .	21,828	29	7	32.1
1897 . . .	22,124	21	1	4.5
1898 . . .	22,423	34	6	26.8
1899 . . .	22,727	52	9	39.6

A comparison of the last column in this table with the death rates from typhoid in other New England cities, shows that Newport has not suffered more severely in the past than have those municipalities whose general conditions are fairly comparable with her own. The figures for the other cities, in Table II, are taken from the monograph on Public Hygiene and State Medicine, prepared by Dr. S. W. Abbott for the United States Commission to the Paris Exposition.

TABLE II.

DEATH RATE FROM TYPHOID FEVER PER 100,000 POPULATION, IN FIVE NEW ENGLAND CITIES, 1895–1898.

City.	1895.	1896.	1897.	1898.
Newport, R. I. . . .	42	32	5	27
Providence, R. I. . .	31	27	15	24
Boston, Mass. . . .	32	31	33	35
Fall River, Mass. . .	33	27	33	21
Worcester, Mass. . .	25	14	14	12

II. EXTENT OF THE OUTBREAK.

It will be noted on inspection of Table I that the number of reported cases of typhoid fever had risen in 1899 to 52, as compared with an average of 29 for the four years next previous. This increase was really even more marked than is indicated by these figures, because, of the 34 cases reported in 1898, 12 were brought to town from Camp

Meade and Montauk Point. There were then twice as many indigenous cases in 1899 as in 1898, and in 1900 the increase proceeded in almost a geometrical progression. The number of reported cases was 127, of which number 108 were of later date than September 1. The weekly distribution of cases is shown in Table III. The dates of cases prior to November 20 were fixed by the day on which the patient took to bed. For the subsequent cases, only the dates of the physician's report of the cases were available.

TABLE III.

WEEKLY DISTRIBUTION OF CASES DURING THE YEAR 1900.

Week Beginning.	Cases.	Week Beginning.	Cases.	Week Beginning.	Cases.
Jan. 15 . . .	1	Aug. 13 . . .	1	Oct. 22 . . .	5
Mar. 19 . . .	1	Aug. 20 . . .	2	Oct. 29 . . .	4
Apr. 23 . . .	2	Aug. 27 . . .	4	Nov. 5 . . .	5
May 21 . . .	2	Sept. 3 . . .	6	Nov. 12 . . .	4
June 4 . . .	1	Sept. 10 . . .	4	Nov. 19 . . .	3
June 11 . . .	2	Sept. 17 . . .	9	Nov. 26 . . .	3
July 2 . . .	1	Sept. 24 . . .	14	Dec. 3 . . .	7
July 9 . . .	1	Oct. 1 . . .	19	Dec. 10 . . .	2
July 23 . . .	1	Oct. 8 . . .	11	Dec. 24 . . .	2
Aug. 6 . . .	2	Oct. 15 . . .	8	Total	127

The number of deaths from typhoid fever during the year was 18, giving a ratio to the population, which according to the Census of 1900 is 23,034, of 78.1 per 100,000. The relation between this outbreak and the amount of typhoid fever prevalent in previous years is seen more clearly from the accompanying diagram, Figure 1, which shows the distribution of cases by months for the past five years.

III. CONDITION OF THE PUBLIC WATER SUPPLY.

The first possible cause which suggested itself to the public in relation to the large excess of typhoid fever in 1900, was the city water supply, and this theory spread the more widely because the Newport water had been highly colored during the late summer, and characterized

by a strongly marked mouldy or grassy odor. This water, which is supplied to the city by the Newport Water Company, is derived from Easton's Pond, a shallow body of water covering about 250 acres to the northeast of the city, and separated into a northern and a southern basin by an artificial causeway. The supply is taken from the more southerly of these reservoirs, and is passed through rapid mechanical filters, with the addition of alum as a coagulant, before entering the force main. This filtration was not, however, carried on with sufficient care to remove the Algæ, which at the time of my visit made the water of the lower basin resemble a sort of gray-green soup. I found in the effluent

FIG. 1. — REPORT CASES OF TYPHOID FEVER IN NEWPORT, R. I., BY MONTHS, 1895-1900.

from the filter plant, filaments of Anabæna and entire colonies of Cœlosphærium, two members of the group of the Cyanophyceæ which have perhaps caused more trouble to water-works superintendents than any related forms. It was presumably to these two forms that the unpleasant taste and odor of the water had been mainly due.

From an epidemiological standpoint, however, a brief inspection of the reservoirs gave no evidence of any serious defects. The south basin of Easton's Pond is protected from surface pollution by a ditch which surrounds it and drains to the ocean. The watershed of the north basin is thinly settled, and the reservoirs are so large as to secure the purifying effects of storage in a considerable degree. A specimen of the water taken from a tap in the town on October 13, gave the following analysis, which, though it shows a large amount of albuminoid ammonia, due perhaps to the vegetable growth, and an excess of nitrates, does not indicate the presence of recent sewage pollution.

FIG. 2. — MAP OF THE CENTRAL PART OF THE CITY OF NEWPORT.

SAMPLE OF NEWPORT TAP WATER COLLECTED OCTOBER 12, 1900.
(Parts in 100,000.)

Turbidity.	Sediment.	Color.	Odor.	Free Ammonia.	Alb. Ammonia.
Very slight.	Very slight.	.35	Dist. veg. Mouldy.	.0018	.0372

Chlorine.	Nitrogen as Nitrites.	Nitrogen as Nitrates.	Hardness.	Bacteria per c.c.	B. coli.
1.86	.0000	.0350	2.6	334	0

Conclusive proof that the typhoid fever was not due to the water supply was found, however, in the geographical distribution of the cases. In a water epidemic the cases appear in all quarters of the town, following the lines of the water mains, being perhaps thickest near the distributing reservoirs, but otherwise occurring about equally in all districts. It is impossible that a general infection carried equally to all parts of a city should produce a large number of cases in a single neighborhood and pass by others similarly circumstanced. In Newport, however, as will be seen by an inspection of the accompanying plans, the great majority of the cases occurred in a limited district of the first ward, twenty-six of them within a radius of 300 feet. On Figure 2, which represents the thickly settled portion of Newport, the cases of typhoid fever reported between the 1st of August and the 20th of November are indicated by the black dots. A moment's study of this map is sufficient to show that some more local source of infection than the city water must be sought.

IV. THE BRIDGE STREET WELL.

The well popularly known as the "Jones Well," at 26 Bridge Street, which formed the supplementary water supply of the affected district, and was frequently used in preference to the city water on account of the coolness of the former, and the color and odor of the latter, was the next object of suspicion. It seemed at first that the cases were distributed so evenly over so long a period of time as to make it improbable that any single cause had been instrumental in all of them. Investigation soon showed that many of the patients had not drunk the well water. It also, however, made it apparent that the cases in which well water had been used, were those most strictly localized in time. While the other cases straggled along rather evenly from week to week, those of this class were grouped together, beginning with one or two isolated cases early in September, becoming numerous after the 15th, reaching a maximum of six cases on the 29th, and declining again after October 7. The well was closed and boarded over in accordance with

my recommendation on the 15th of October, and after October 29, or the lapse of the average incubation period for typhoid fever, only three cases have occurred in the community using the Jones Well, and all three were return cases traceable to personal contagion. (See Figure 3.)

We find then, thirty-eight cases of typhoid fever occurring between September 16 and October 23 in a limited district and among a population using a special source of water supply. This source of supply was a shallow well about 10 feet deep, and 8 feet in diameter, with sides of uncemented stone and a covering of planking, upon which those who

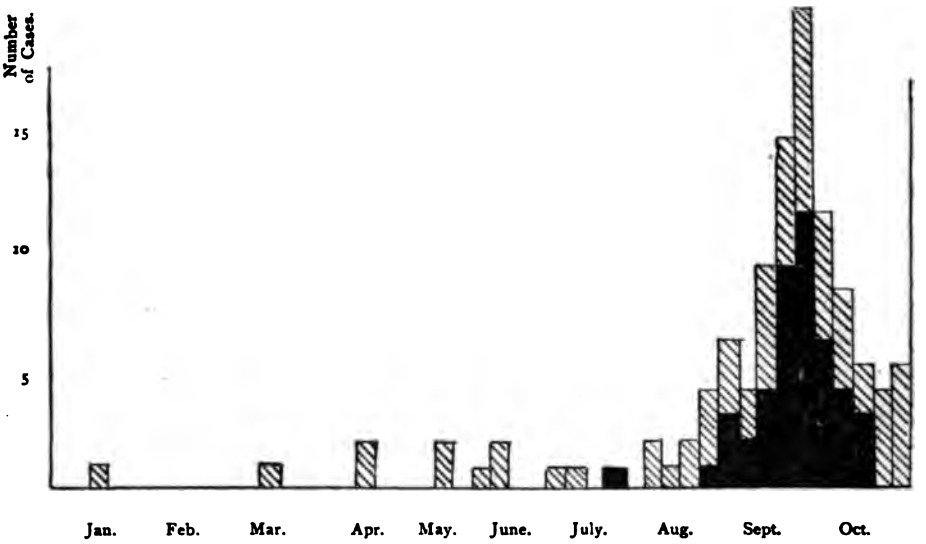

FIG. 3. — REPORTED CASES OF TYPHOID FEVER IN NEWPORT BY WEEKS, DURING THE FIRST TEN MONTHS OF THE YEAR 1900.

The black columns indicate those cases in which the Bridge Street well had been used for water supply, the cross-hatched columns represent those cases in which there was no such history.

used the water stood while operating the primitive wooden pump by which it was raised. The watershed, sloping gently to the east, included some twenty privy vaults within 400 feet, the nearest being in the rear of Numbers 28 and 26 Bridge Street, respectively 25 feet and 60 feet to the southward (Figure 4). The water level in the well was about 2 feet below the surface of the ground, so that the material from the vaults could pass laterally through the filth laden and water soaked soil without any downward filtration whatever. The following analysis of the well water fully confirms the conclusion drawn from a sanitary inspection — that the well was grossly contaminated.

SAMPLE OF WATER FROM WELL AT 26 BRIDGE STREET, COLLECTED OCTOBER 12, 1900.
(Parts in 100,000.)

Odor, cold.	Odor, hot.	Free Ammonia.	Albuminoid Ammonia.	Chlorine.
F. musty.	None.	.0248	.0068	8.30

Nitrogen as Nitrites.	Nitrogen as Nitrates.	Hardness.	Bacteria per c.c.	B. coli.
.0500	.8500	12.11	6100	Present.

FIG. 4. — SKETCH PLAN OF PART OF THE WATERSHED OF THE BRIDGE STREET WELL.

Each black circle indicates the occurrence of a case of typhoid fever, between August 30 and October 30, 1900.

If typhoid germs can ever be carried through the earth, they could be carried from the dejecta of a typhoid patient in one of the neighboring vaults to a well of this character. That such dejecta were present is certain. On August 31, there was a case of typhoid fever at 11 Bridge Street, with a vault about 200 feet northeast of the well, and on September 3, there was a case in Cozzens Court with a vault 300 feet

southeast, (see Figure 4). It is easy to conceive, especially as I f that the excreta had not been disinfected in these early cases, t slight amount of infective material may have found its way from o these sources to the well, and caused the first few cases. One of t first cases, already sick with what proved later to be typhoid fever 28 Bridge Street on September 15. The vault in which the excre this patient were received was only 25 feet from the well; and it is easier to conceive that infection passed through this short distance caused the later outbreak which culminated with twelve cases in week of October 12. In some such way, either by percolation thr the open soil or by accidental infection from the top, the well, i judgment, became infected, and caused about one-third of the c making up the total outbreak.

V. Other Possible Vehicles of Infection.

The fact that no large number of typhoid fever patients had a mon milk supply, excludes that important factor in the transmissio disease. Among the one hundred and ten cases investigated, (u November 20), there were thirty-one milkmen; the greatest nur of affected families on any one route was five, and in these the c did not occur simultaneously. Two apparently sporadic cases r however, have been due to this cause. Case Number 30 was a milk supplying from twenty to thirty families in a district quite outside region where the main epidemic was localized. He cared for the er business in person, as well as for the delivery of the product. On tember 15, he took to his bed with typhoid fever; every precaution at once taken for the future, and the milk business was put in ch of another person not connected with the household. On Octob and 6, however, two of the customers on this route fell ill, the dis in one instance terminating fatally. It is possible that these two c may form a miniature milk epidemic such as might often occur wit attracting attention.

A large proportion of the typhoid patients had purchased ice-cr from a shop kept by a dealer on Bridge Street, and I was inclinec first to consider this fact significant. It proved, however, that this the popular source of supply for the entire neighborhood, the healthy well as the sick. Of the thirty-one cases among the customers of shop, between September 1 and November 15, eighteen were also u

of the Jones Well water, and the thirteen remaining were so widely scattered in time as to rule out the possibility of a common source of infection. Furthermore, an investigation of the shop in question, and of the origin of its various supplies failed to reveal any apparent opportunity for contamination.

A majority of the households stricken by the epidemic did not use ice. Those who did so, obtained it from one of two companies, both of which have delivered during the summer a mixed supply of artificial ice and natural ice, supplied by the Boston Ice Company. The cases among the ice users did not occur in greater number at any special period so as to warrant any suspicion of this supply as a cause of the epidemic; and hundreds of persons in other districts of the city used ice from the same sources without ill effects.

Finally, there was no common source of supply for green vegetables among the typhoid patients, and only a very few of them had been in the habit of eating raw shell fish.

VI. Influence of Sanitary Conditions.

No common cause was then found for the residuum of cases not connected with the Bridge Street well. This is exactly what one would expect after an examination of Figure 3; for if the Jones Well cases are eliminated, it appears that the fever did not strike a sudden blow at a definite time, but has exercised a more or less constant pressure since early in August. Not a week between August 20 and December 17 passed without at least two cases outside of the well users, and in only two weeks did the number of such cases exceed five. The well, if my conclusions are correct, caused an epidemic in the last part of September and the beginning of October; the other cases formed not a sharp epidemic outbreak, but rather such a slow succession of isolated cases as the older sanitarians termed "endemic." This term has been so misused, so associated with the idea of some mysterious miasm inherent in a geographical region, that it has fallen into deserved disrepute. It is, however, vital for the epidemiologist to distinguish this process clearly from the infection which reaches a number of persons at once through a single medium, such as water or milk. I have ventured to coin the term *prosodemic*, "through, or among, the people," for this form of disease which progresses gradually from person to person by routes which, whether direct or indirect, are different for each individual case.

The term "epidemic" I should restrict to that special case in which circumstances permit the transfer of infection to a large number of persons through the same medium, and at approximately the same time.

The methods by which prosodemic typhoid may spread are almost infinite. The last link in the chain is, in most cases, some sort of food or drink; and the food becomes directly infected, in many instances, from the hands of the typhoid patient or of his unprofessional attendants. The transmission of typhoid fever on a large scale by water and milk, has led sanitarians to minimize unduly the direct personal element in its etiology; but the fact that two trained nurses were stricken down during the year in Newport, recalls the possible importance of this factor. Another mode of conveying disease, to which we have learned to attribute an increased significance within the last few years, is the carriage of infected matter by insects; and there can be no doubt that many mysteriously sporadic cases of typhoid fever are conditioned by the passage of a fly from an infected vault to an unprotected table or an exposed larder. At the other end of the chain, however, there is in almost every case of prosodemic infection some disregard of sanitary cleanliness. Hands, insects, and food can only become contaminated when infective material has not been properly removed and cared for. An epidemic affecting a great number of persons through water, milk, or oysters, may be due to a single act of carelessness or ignorance. It is only, however, among a dirty population in unsanitary dwellings that typhoid fever becomes actively contagious. It is, therefore, instructive to note that of the premises upon which typhoid developed in Newport, I inspected eighty-one, and found that forty-two were provided with privy vaults, and only thirty-nine connected with the sewer; and of the former, twenty-one at least were in a foul and dangerous condition.

As has been said, the infection by means of filth and fingers, of flies and food, proceeds by a different path and at a different time in each case, and is generally impossible to trace in detail. In certain instances, however, the probable course of contagion from person to person is clearly indicated; a few such chains of evidence I have collected in the Newport outbreak, of which the following selected examples are perhaps the best.

1. Case Number 76, a teamster, exposed in his work to many opportunities of infection, developed the disease at his home on Harrington

Street, October 10. On October 23, or after the lapse of two weeks, the average period of incubation for typhoid fever, case Number 95, a fellow teamster, boarding at the same house fell ill. On December 6, a third case, Number 119, was reported from the same house.

2. On August 12, case Number 14 developed in a house on Thames Street, the patient being a little girl who had come from New York State two weeks previously, probably bringing the infection with her. On August 28, her nurse, case Number 18, was taken sick; and on September 17, her grandmother, living in the same house, fell ill in turn with the disease.

3. Case Number 80, a domestic employed on Powell Avenue, left that place September 25, to nurse a cousin who was suffering from "diarrhœal trouble," on Bridge Street, opposite the Jones Well and in the thick of the epidemic. On October 9, she returned to Powell Avenue, and on October 12 she took to her bed with typhoid fever. She is said not to have drunk the well water while in Bridge Street.

4. Case Number 84 was a boy of thirteen, living in Spruce Court, who sold papers in the Bridge Street district, and probably contracted his disease from the well water. He fell ill on October 14. His mother worked for a family across the way, and went over, to assist in the preparation of the food, from the bedside of the invalid. On October 31, case Number 99, a young woman in the house where the mother worked, fell ill with the fever.

5. On October 9, case Number 75, a girl in a family on Long Wharf, developed the disease, probably derived from the Bridge Street well. On November 14, her sister, on November 16, her mother, on November 21, her brother, and on November 24, another inmate fell ill, although by this time the well had long been closed and the general epidemic had subsided. The premises in this, as in most of the other instances where return cases occurred, were dirty and ill-kept.

6. On the 15th and 19th of October, two cases occurred among the customers of a steam laundry on Mill Street. On the 9th of November, case Number 104 developed, the patient being a young man engaged in that laundry in the process of sorting the clothes.

7. Case Number 21 was a young lady living in Thames Street very near Bridge Street and the infected district, who was taken sick September 1, the source of infection not being apparent. Her niece, a little girl of seven, who lived in Channing Court, in another quarter of the city, but spent much time with her aunt in Thames Street, developed

the disease at the same time, and was sent home to Channing Court, where her brother, ten years old, case Number 53, fell ill on September 29, and her sister, aged three, case Number 82, followed on October 13.

VII. Lesson of the Outbreak.

After the closing of the Bridge Street well, the typhoid outbreak did not again become severe, and with the onset of cold weather there was a gradual decrease in the number of cases due to contagion, until in the last two weeks of December, there were only two cases reported, and in January, 1901, there was only one case. With rising temperature, however, the typhoid rate has also began to rise, as is its wont. In February there were three cases, and in March, four; a small number, but large enough to be menacing, in view of the fact that there were only three cases in these two months last year.

The way in which the typhoid germ survives the winter and begins the steady increase which culminates in an October maximum, is well shown in the Newport records. This bacterium does not ordinarily live very long, at least in large numbers, outside the human body, under the damaging effects of cold, light, dryness, poor food, etc.: but in heaps of excrement there is reason to believe that it may survive for many months. From germs preserved in this way it seems likely that the 1900 outbreak started. Cozzens Court is a short street parallel to Bridge Street, inhabited mostly by negroes, and its vaults and the whole surroundings were in an exceedingly filthy condition. There were four cases of typhoid fever in this court in 1899, the first on August 11, the second and third at Number 7 on August 26 and September 26, and the fourth at Number 2 on October 27. The first case to occur in the Bridge Street neighborhood in 1900 appeared with no apparent outside source of infection at Number 7 Cozzens Court on July 12; the second at Number 2 Cozzens Court on July 27. Of the two cases to which I attribute the contamination of the Jones Well, the first was at 11 Bridge Street, a stone's throw from the cases mentioned, and the second was again at Number 2 Cozzens Court. The same thing has apparently happened during the winter just past. It can hardly be a coincidence, that of the four cases reported in March, 1901, two are from a house on Thames Street provided with a privy vault in which there was a case of typhoid fever in October, 1900.

To prevent the preservation of typhoid germs through the winter, and the sowing of them broadcast during the summer, there are two remedies — their destruction or the removal of the vehicles by which they are spread. First, then, disinfection suggests itself as an available weapon; and I submitted to the Newport authorities a complete schedule for the treatment of excreta, of clothing and bedding, and of infected walls, floors, and woodwork. Much good work was done in this direction. Most of our processes of disinfection are, however, incomplete, and even if every typhoid bacillus present at a given time could be exterminated, the filth which furnishes means for keeping alive and distributing imported germs would remain a constant menace. The one vital fundamental remedy is sanitation — the closing of shallow wells, the cleaning of the streets and yards, and in particular the removal of the vaults which may preserve typhoid germs in active condition for long periods, which pollute the ground and ground-water in their neighborhood, which foster habits of personal uncleanliness, and favor the transmission of disease both by contagion and by the agency of flies and other insects.

It is because it calls attention to the sewell-known but often forgotten dangers that the Newport outbreak is of interest. Newport is no worse than many American cities. We have been right in considering water as the most important vehicle of typhoid fever. That lesson has now been learned, and most of our cities put sufficient value on human life to protect their sources of drinking water. The next most important vehicle of typhoid fever, in my opinion, is filth, and to this our attention should be increasingly turned. The sewer-gas fetich of the British sanitarian has led him into some absurd excesses; but it has worked most effectively for civic cleanliness. Few English, and fewer German communities would endure the typhoid death rates which weigh year after year upon the best American cities. What is the reason for our excess; is it infected water, milk, and shell-fish, or merely filth? It is incumbent upon us to find out. For the typhoid death rate is the reciprocal index of civilization.

THE TRIPOLITE DEPOSIT OF FITZGERALD LAKE, NEAR ST. JOHN, NEW BRUNSWICK.

By W. O. CROSBY.

Among the numerous deposits of tripolite in the fresh-water lakes and swamps of the Maritime Provinces, some of which are, no doubt, destined to prove of considerable economic importance, it would probably be difficult to find a deposit of considerable magnitude which is, on the whole, of more special interest to the student of geology than that of Fitzgerald Lake. In some respects this deposit is unique, and it is particularly so in the simplicity of its history, which permits us to regard it as a type of which many other deposits are more or less widely divergent variations. The essential conditions of the accumulation of a notable deposit of organic silica in a state of approximate purity are exhibited in Fitzgerald Lake so free from complications as apparently to justify placing on record the results of a study made several years since, although the explanation which the facts have suggested may be wholly lacking in originality.

Fitzgerald Lake is between seven and eight miles northeast of St. John, on the Loch Lomond road and on the headwaters of Little River. It has an elevation of 290 feet above high tide, and is bordered by a wooded plain of coarse gravel (modified drift). On the east and south sides of the lake the land rises 30 to 50 feet to form a winding ridge (probably an esker) which encloses Latimer Lake, the chief reserve of the St. John water supply. Latimer Lake, which is naturally tributary to Mispeck River, had an elevation of 302 feet before its outlet was dammed, and its outflowing waters turned through a low cut in the ridge down through Lake Fitzgerald into Little River. On the northwest, the plain of modified drift enclosing the basin of Lake Fitzgerald falls gently away toward Little River, descending 70 feet in one-fourth to one-half mile. Fitzgerald Lake is reached on the north side by a short branch from the Loch Lomond road, and a road following more closely the valley of Little River passes within a short distance of the south side of the lake.

Fitzgerald Lake was drained several years ago by the cutting of a shallow trench across the narrowest part of the bordering plain, and is

now a grassy meadow, with the overflow from Latimer Lake passing through one corner of it in a narrow artificial channel. The area of the lake is 74 acres, and it is estimated that approximately 60 acres are underlain by the tripolite. Its outline is an irregular oval, a broad reëntrant curve indenting the northwest side; and here the bottom is of a rough stony character for a breadth of 100 to 200 feet, the depth having been insufficient to permit the formation of any deposits. Considering its area, the lake was very shallow, the maximum depth having been less than five feet. The greater part of the lake is now well grassed over, the grass forming quite a strong turf, over which with due care it is possible to walk without breaking through. The tripolite is practically the surface deposit; in other words, it is not covered by clay or peat or anything except this thin turf, and considerable patches of the tripolite are entirely bare, even of grass.

With suitable lengths of one-half-inch gas pipe, a series of soundings was made across the lake in different directions to test the depth and quality of the tripolite, and in this way it was proved, not only that the deposit has a considerable depth, but that the tripolite is continuous from the surface downwards; that is, it is not interstratified with clay or peat. In some cases the pipe struck a hard, stony bottom, and in others penetrated a firm, semi-hard form of the tripolite, a bottom layer which has probably no great thickness. Above this layer, which proved on examination to consist largely of quartz flour, the tripolite is uniformly soft and slimy, the gas pipe passing through it almost of its own weight. The surface of the bog, or lake bottom, is very quaking, and but for the density (specific gravity) of the underlying tripolite jelly, walking over it would be dangerous. The thickness of the pure or approximately pure tripolite varies from a foot or less near the edge of the deposit to ten or twelve feet in the central portion, and an average depth of five feet seems a safe estimate. It is very clear that the deposit is all tripolite down to the level where it begins to change gradually into the quartz flour, which becomes at last so compact and firm that the gas pipe was with difficulty forced into it, and the quartz flour shades off at some points into ordinary fine sand. The covering of grass grows directly on the tripolite, and it is evident heretofore that the lake has always been flooded, for there is nowhere any appreciable amount of peat over the tripolite. This lake basin must have been originally a large and comparatively shallow kettle-hole, having a maximum depth of twenty or possibly twenty-five feet in the plain of modi-

fied drift; and it is now filled nearly to the brim with this slowly formed, organic deposit, which, in its present super-saturated condition, is like a quaking siliceous jelly, with only a thin cover of turf, and with a substratum of quartz flour from one to ten feet in thickness. The tripolite is naturally of a gray to dark brown color, due to the presence of organic matter, which is readily burned out; and after calcination the material is nearly white, being but slightly tinged with iron oxide.

An analysis of a calcined sample gave the following result:

Soluble silica	82 per cent.
Insoluble silica in the form of impalpable quartz flour . .	17.5 per cent.
Clay, iron oxide, etc.	traces.
	99.5 per cent.

In searching for the explanation of this deposit it is important to note: that the catchment area, or watershed, of this basin (kettle-hole) is very limited; that there were naturally, or before the diversion of Lake Latimer, no tributary streams; that the surface is of such character (chiefly coarse gravel) as to afford little or no rain wash, especially as it is, and probably always has been, covered with forest and a thick layer of vegetable mould; and that the conditions are very unfavorable for the introduction of wind-borne dust. Mechanical silt has thus been almost wholly excluded, and a continuous cover of water has prevented the formation of peat.

Water percolating through the layer of vegetable mould over the surrounding surface has penetrated the underlying gravel, where the carbonic and organic acids with which the water is now charged, have slowly decomposed the silicate minerals (feldspar, hornblende, etc.) of the numerous pebbles of granite, felsite, diorite, etc., forming carbonates of the alkalies and alkaline earths and liberating an equivalent amount of silica, which, being soluble in water holding alkaline carbonates, is carried in solution into the lake, where it is appropriated by the diatoms with which the waters swarm.

An alternative hypothesis is based primarily on the well established fact that several of the humus acids, and notably azohumic acid, are efficient solvents of silica, which will be precipitated when these acids are converted by oxidation to carbonic acid, by the oxygen exhaled by diatoms, as by all other forms of vegetable life. This explanation would enable us to derive silica directly from quartz, and not exclusively from the silicates.

The process is probably essentially chemical at every step, although the precise nature of the reaction of the organism upon its medium, determining the deposition of silica in or upon its body, is still undetermined. This slow process of the leaching of silica from the surrounding gravel through the agency of decaying organic matter, and its precipitation by the diatoms in the forms of their exquisitely fashioned frustules has been uninterrupted for thousands of years; until the resulting deposit of tripolite completely fills the basin of the lakelet. Meanwhile, but little sand and clay have been washed from the shores of the lake by its feeble waves, and the surrounding forest has protected the lake from wind-blown dust; but the deposit of nearly pure tripolite is, under existing conditions, being overspread by a layer of peat. The uncompacted and quaking consistency of the tripolite has probably tended to keep it pure by permitting such mechanical detritus as did find its way into the lake to settle to the bottom, and thus, probably, the substratum of quartz flour blending upwards with the tripolite has been chiefly formed. A further condition essential to the formation of tripolite and realized here, is the absence of an outflowing stream. Like so many of our kettle ponds and lakes, this is a closed basin from which the water escapes only by seepage and evaporation. The silica leached from the surrounding gravel and the organisms essential to its precipitation in the solid form are thus retained in the basin; and the cycle of chemico-organic erosion and deposition is completed in a limited area; for through the combined agency of decaying organic matter on the land, and living organisms in the enclosed and stagnant, but limpid, water is effected a gradual transfer of silica from the hard, insoluble silicates of the gravel and its deposition in a pure but hydrated and opaline form in the bowl-like depression left by the melting of a buried remnant of the great ice-sheet.

ON THE APPLICATION OF BACTERIOLOGY TO CERTAIN ARTS AND INDUSTRIES.[1]

By SAMUEL C. PRESCOTT, S. B.

During the last four decades of the Nineteenth Century the advance of scientific knowledge brought to light many new and interesting discoveries, not the least important of which were in the domain of biology. Of greatest value, perhaps, was the work upon the micro-organisms, and especially upon that class of micro-organisms known as bacteria, and which led to the establishment of the germ theory of disease, which has practically revolutionized the art of medicine, and has been the creator of the science of sanitary engineering.

It would be impossible to overestimate the value of the discoveries made in this field, and it is not surprising to find that interest in the bacteria has in years past centred largely in their sanitary and pathological relations, although it has long since been shown that the disease-producing species constitute but a small proportion of the bacteria now known.

It is of interest, however, to bear in mind that the discoveries which proved of most value in establishing the germ theory of disease were made along lines affecting, not the health of any people, but its economic and industrial relations. The work of Pasteur on undesirable fermentations of wine and beer, and his later work upon the silk-worm disease, which seemed likely to bring utter ruin to the silk industries of France, demonstrated in a most efficient manner that certain specific organisms endowed with definite morphological and physiological characters gave rise to specific and characteristic troubles or diseases, and led to the theory that each disease and each fermentation has its specific exciting organism. The triumphs which have resulted in preventive medicine have amply proved the significance of this discovery to humanity, and proclaim it perhaps the greatest achievement of the century.

It is not only on the pathological and sanitary sides of the subject, however, that bacteriology has made its advance. The technical side

[1] Read before the Boston Society of Natural History, March 6, 1901.

has not been overlooked, but on the contrary has made gigantic strides, leading to the establishment of experiment stations and laboratories for the investigation of fermentation problems, and for the development of those branches of industry wherein micro-organisms play an important part. To the manufacturer, chemist, or technical man this new subject of industrial bacteriology appeals even more strongly than does the pathological side of the subject, and that popular interest in it is less, is largely because of its recent growth, and because the facts underlying this fascinating branch of applied science have not been sufficiently elucidated.

I desire, therefore, to consider certain phases of the subject of industrial bacteriology, and to show, if possible, how a knowledge of micro-organisms may be applied to productive or manufacturing processes. This can best be done by describing the predominant rôles — both useful and antagonistic — which are played by some of the micro-organisms; useful, when we employ certain species to bring about desired chemical changes; antagonistic, when the growth of the organisms, if unchecked, would give rise to harmful or undesirable substances and thus result in commercial loss. Thus we may consider here the part acted by micro-organisms in the manufacture of vinegar and lactic acid, in baking, brewing, and wine making, in the preparation of skins for tanning, in the dairy and sugar industries, and in certain agricultural processes, and so on through a long list of reactions formerly believed to be purely chemical in character, but now recognized as being intimately bound up with the vital processes of living organisms.

To all these manifold transpositions of organic substances thus produced we give the term fermentation, so that our science of Industrial Biology is in reality a science of fermentation, using this term in its widest sense, for this word has broadened in meaning as the knowledge of such processes has increased, and has far outgrown its original significance. We no longer think of fermentation as merely the transformation of sugar to alcohol and carbon dioxide, but as a term embracing a multitude of chemical reactions, all being alike in the one respect, however, that the ultimate cause is a living cell. Before considering the specific fermentations in detail, some further general statements as to cause and manner of action may be of interest.

Let us first consider the organisms themselves which may be utilized to bring about these fermentations. The industrial bacteriologist deals not only with bacteria, but also with certain other colorless plants or

fungi, for many moulds and yeasts, as well as bacteria, are of technical interest

Leaving the systematic botanical position out of account for the moment, the above mentioned organisms possess certain characteristics in common. The most striking is, of course, the ability to produce fermentative changes of chemical and industrial significance. Not less important from the point of view of the fermentation chemist and physiologist is the fact that all these organisms may be made to grow in pure cultures in or upon specially prepared nutrient media, and hence their activity and power to induce fermentative changes may be studied with a considerable degree of certainty. As the methods employed for this purpose are modifications of those originally designed for the study of the bacteria, or bacteriological methods, it is convenient to class all the organisms which may be so studied as "bacterial organisms," as has been recently suggested by Professor Sedgwick,[1] when speaking in general terms, although more specifically one would refer to the generic name, or at least to the class name.

Briefly stated, the three classes may be characterized as follows:

The moulds are colorless branching organisms, increasing vegetatively by means of apical growth, and normally reproducing by the formation of spores, either in a special closed body, or sporangium, or in rows like strings of beads with no retaining covering. They occur abundantly on dead organic matter of suitable composition, especially carbohydrate; grow with great rapidity, producing a mycelium, or mass of growth easily visible to the naked eye; and, except under special conditions, give rise to only very small amounts of fermentation products. Grown submerged in sugar solutions, without access of air, they give rise to a vigorous alcoholic fermentation. They prefer an acid medium.

Of greater importance are certain of the *yeasts*, as employed in bread-making, brewing, and wine-making. These are small oval or rounded organisms which increase in numbers rapidly under favorable conditions by a process of budding, that is, a cell produces at one end a little outgrowth, or knob, which develops to nearly the size of the parent cell, and then becomes independent by the formation of a dividing wall, although it may still remain attached to the older cell. The yeasts are especially active as producers of alcohol and carbon dioxide, and upon this activity their industrial value depends. In size

[1] W. T. Sedgwick, "On the Origin and Scope of Bacteriology." Presidential Address before Society of American Bacteriologists. *Science*, January, 1901.

they are intermediate between moulds and bacteria, the smallest known organisms.

Although smaller and presumably simpler, the *bacteria* have much greater diversity of fermenting power, yielding a large variety of substances. Their general appearance is rod or ball-shaped, and their ordinary method of growth is by simple fission, or the splitting of one organism into two. Here, too, growth is extremely rapid when conditions are favorable. Many kinds are able to produce extremely resistant bodies known as spores, whose function is apparently to perpetuate the life of the species during periods when the environment is unsatisfactory for the normal vegetative development.

Along with the increase in our knowledge of the number and varieties of fermentations and ferment organisms has come also a better understanding of the way in which these minute cells are able to carry on their characteristic actions. It has been possible, by careful investigation, to penetrate into the living laboratory, and to find out in an imperfect way the kinds of reagents which the cell uses in its chemical work.

It has for a long time been known that certain cells, as for example those of sprouting grain, were able to bring about the change of starch into maltose and glucose, the process familiarly known as malting. It has also been known that yeast could bring about a similar change from cane sugar to glucose, and that the latter substance was then "fermented" or split into alcohol and carbon dioxide. The power to bring about these chemical changes was found to be due to certain soluble substances of complex nature which could be isolated from solutions containing them, and to which the name "soluble ferments" was first given, but which are now spoken of most frequently as *enzymes*. Similar substances were known to be produced by certain cells in animal organisms, as for example, the pepsin of the gastric juice and the trypsin of the pancreatic juice, which react almost exactly as plant enzymes do. From time to time new enzymes have been discovered, until at the present time there seems little reason to doubt that fermentation as we know and can study it, is entirely the result of enzyme action, although it must ever be borne in mind that the living cell is the ultimate cause since it is the producer of the enzyme. These enzymes, as has already been stated, can be precipitated or otherwise separated from the cells producing them, and in the isolated condition can give rise to the characteristic action which determines the fermentation,

although the powers of the enzyme are in some cases weakened by such separation. The reason for this is, perhaps, because of the crudeness of the methods of preparation to which we have had recourse up to the present time. In fact, we have no way of determining with certainty whether the enzyme as prepared is in a state of purity or not, and the chances are very favorable that our most successful attempts are far from perfect. Moreover, we know that these substances are extremely sensitive to certain chemical compounds, bases and acids, and thus will act only under somewhat limited conditions.

All enzyme action is characterized by the fact that a small amount of the active agent can transform a comparatively large amount of the substance acted upon, and without itself becoming used up or destroyed. Thus it has been shown that in the conversion of cane sugar to glucose a given weight of the diastase can easily transform 100,000 times that weight of sugar, and with no apparent loss to itself. Sometimes the same chemical change can be brought about by purely chemical means; for example, the conversion of cane sugar just referred to can be produced by boiling with dilute acids; or, to take another example, albuminoid substances, which are generally changed to peptones by the action of enzymes, can undergo the same change, to some extent at least, on being treated with steam under pressure. Notwithstanding these facts, there still exists a great difference between this chemical work and the physiological work of cells.

In order to favor chemical reaction one often makes use in the laboratory of very violent means, perhaps a strong acid or alkali, high pressure or a high temperature. To produce, for example, an oxidation process one may use reagents such as nitric or chromic acid or potassium permanganate. As a dehydrating agent, concentrated sulphuric acid, or anhydrous phosphoric acid, or zinc chloride may be used. When one works with living cells, on the contrary, the reactions take place in media of nearly neutral reaction, and the temperature is always moderate and nearly constant. The difference between these two methods of action is most striking. In the living cells there takes place the reaction of bodies which, according to our generally accepted ideas, have only weak affinities. We observe at the same time that substances which we ordinarily regard as very stable are decomposed within such cells with great facility.

Three varieties of chemical action have been recognized among the enzymes; first, and most frequent, a hydration, generally, but not always,

followed by a splitting of the compound into simpler substances; second, oxidation; and third, molecular decomposition into simpler compounds without hydration. Having thus broadly defined the fermentation organisms and the way in which they act, let us now consider in greater detail some of the processes of industrial importance in which these organisms play a part.

We may begin with the alcoholic fermentation, since this is the one which has received the most attention, is of most interest historically, and offers a large field for the microbiologist in dealing with the many problems presented. Four industrial processes may be here considered: brewing, wine-making, fermentation for panification, and fermentation for distillation. In all these certain yeasts are depended upon to give the desired result, and it is recognized that other yeasts or other kinds of organisms might be of great injury in giving rise to by-products of an undesirable nature. Thus, in bakeries, yeast is used to give lightness and a certain texture and flavor to the bread. The mixture of flour and other ingredients is heavily inoculated with yeast and put at a moderate temperature to "rise." Diastatic enzymes in the flour itself bring about the inversion of some of the starch present, and the yeast soon sets up a vigorous alcoholic fermentation, the bubbles of carbon dioxide formed becoming enclosed in the thick dough, and thus making it more or less spongy or porous in texture. The effect of temperature here is very marked; if too high a temperature be used in raising the bread, sourness will result, caused by the fermentation of the sugar, not to alcohol, but to lactic acid, by bacteria which are present in the flour or as an impurity in the yeast. So long as the temperature is kept low enough these act but feebly, partly because of the antagonistic action of the yeast, and partly because of the fact that their optimum temperature is above that of the yeast organisms. If, however, the bacteria are present in great numbers, they may begin action at once and practically outstrip the yeast in action, therefore it is essential to use a yeast culture which is vigorous and at the same time relatively free from bacteria. There are, perhaps, certain bacteria which help out in the process of bread-making, and some authorities claim that bacteria are necessary, an assertion which cannot be accepted at present, at least not for American bread.

The essentials of a good bakery yeast are activity in fermentation, and large carbon dioxide production, and it must not impart a disagreeable taste or odor to the bread; hence great care should be employed in selecting a bread yeast. The ordinary compressed yeast of commerce

is, in general, distillery yeast which has been washed, mixed with starch or meal, and wrapped in foil to keep it moist and to prevent the invasion by moulds and bacteria. Brewing and wine-making, to be successful, are also dependent upon good yeast. In several continental European countries the fermentations are carried on in some places by use of pure cultures of species of yeast, which are found by experiment to give a satisfactory product. In this way all objectionable organisms, known as "disease organisms," are avoided. In America, however, the use of pure cultures in brewing has made but little headway, as it is claimed that by general cleanliness and care better results can be obtained than with the use of complicated apparatus such as is necessary in using the pure cultures. Moreover, under these circumstances the yeast remains fairly pure and resists action of foreign germs to a considerable extent. In England, also, pure cultures have not been found successful for ale fermentation. Among the "diseases" with which the brewer has to contend in this country are those which give cloudiness and turbidity, and brewers often claim that Americans drink with their eyes rather than their mouths — meaning that appearance counts for more than taste. The present tendency, in certain localities at least, is to get a product high in carbon dioxide, relatively low in alcohol, and bright and clear in appearance. Hence the "culture" yeast employed must be selected with care, and the disease-producing organisms eliminated so far as possible — a process involving a certain amount of technical skill.

In wine-making the process is somewhat different, and the manufacturers are still to a great extent the victims of chance, since they depend almost entirely upon the yeast which gets into the grape juice "spontaneously." The skins of the grapes are covered with cells of various kinds, among them the species of yeast which are of most use in carrying on the fermentation of the juice. Disease organisms have much readier access here than in brewing. Brewing and wine-making differ in several important respects. In brewing certain grains are employed as sources of sugary material, while wine-making deals directly with fruit juices, generally grape juice. In brewing the sugars fermented are maltose and dextrose, and perhaps levulose; in wine-making, principally fructose and dextrose. In brewing we have practically the sterilization of the liquid before the addition of the yeast, while in wine-making this is not the case. Finally, the yeast itself is different in the two cases.

In fermentation for distillation yeasts are used which act with great

vigor and give rise to large amounts of alcohol in a short time. Here it is not always necessary to be so careful as to minor details, as the main object sought is a high yield of alcohol. Certain conditions may prevail, however, which render a vigorous fermentation and large yield of alcohol impossible, unless care is taken. Should conditions favor the development of butyric acid bacteria, which are likely to be present in the mash in large numbers, trouble may result, since this acid, even in very small amounts, is extremely poisonous for yeasts; hence means must be used to prevent its formation. This is done by the introduction into the mash of a small amount of lactic acid, which is poisonous for the butyric organisms and beneficial to yeast rather than harmful. Hence if lactic acid in the proper amount be added to the mash before the yeast is added, the vegetative butyric bacteria and their spores are prevented from doing any damage and the alcoholic fermentation goes on without interruption. Practically the same result may be brought about by the action of ammonium fluoride or bismuth nitrate, salts which restrain bacterial action, but in small amounts are harmless for yeast.

Researches carried on during the past three or four years have shown that the yeast brings about the splitting of sugar to alcohol and carbon dioxide by means of an enzyme known as zymase, which exists within the cells, and from which it may be obtained by grinding with fine sand and then subjecting to pressure. The resulting substance is an opalescent yellowish liquid which will bring about the fermentation process much as yeast itself will, although less actively in some respects. Investigations as to the real nature of the press sap are now being pursued by a number of workers, for some of the most interesting questions as to enzyme action and fermentation in general are thereby awaiting solution.

One should not leave the subject of alcoholic fermentation without a brief reference to certain symbiotic relationships between yeasts and bacteria. The best known of these are the "ginger-beer plant" of England and the "kephir" of the Caucasus, used in fermenting the drink koumiss, the substance in both cases being mixtures of yeast with one or more species of bacteria growing together in the form of lumps or granules, and acting simultaneously when put in suitable media, giving rise to small amounts of alcohol and lactic acid.

Closely related to the alcoholic fermentation is the acetic, or the oxidation of alcohol to acetic acid by bacteria, as in the process of

vinegar-making. This process has been known and employed for a long time, but still it is only comparatively recently that accurate knowledge has been obtained as to the organisms involved, and even now many suppose that the process is a case of simple chemical oxidation Through the investigations of Hansen, and more recently of Lafar and Henneberg, it has been shown that there is a group or race of bacteria which will develop most rapidly in dilute alcoholic solutions, and if the temperature be favorable, will oxidize them to acetic acid and water, with sometimes the formation of an intermediate product aldehyde.

The bacteria which bring about this transfer of oxygen from the air to the organic substances in solution present many interesting features aside from their remarkable chemical activity. Although seen to be in the form of short rods when in normal condition, soon after being put into a weak alcoholic liquid, as cider or beer, they develop rapidly into thick gelatinous surface layers, which are true zoöglœa masses. These eventually sink to the bottom of the containing vessel, forming the "mother of vinegar." With changes of temperature the bacteria undergo strange changes in shape, becoming much elongated and often swollen so that they present no similarity whatever to the original form. Such bacteria are widely distributed in nature, living especially in the earth under fruit trees and on the fruits themselves; hence, as a rule, they are constantly present in fruit juices, as in sweet cider. The different species show some variation in their action, some being of far greater value in vinegar production than others, owing to the formation of pleasant-smelling ethers of fruity odor, as well as a clear, sharp vinegar; while others produce less pleasing results, or may even oxidize the acetic acid completely to carbon dioxide and water, thus being of injury rather than benefit to the manufacturer. Here, then, is the problem for the bacteriologist: to separate the good from the useless, and to cultivate them in the pure state, if experiment shows that the best results are to be obtained in that way.

In the various lines of dairy work the bacteria play a most important part. Not only is the souring of milk brought about by microörganisms, but certain processes, known as the ripening of cream and the ripening of cheese, are due to their action. The finest butter is that made from cream in which certain bacteria have carried on fermentations, giving products of delicate flavor and aroma, and such bacteria are now to be obtained as articles of commerce under the name of

"butter culture." These butter cultures may contain a single species of organism, or may contain a flavor-producing species and a souring species, for experience has shown that if lactic acid is formed at the same time as the flavor-producing substances, the quality of the butter is improved. The chief advantages to be derived from the proper use of butter cultures are three:

1. Certainty of good product.
2. Uniformity of product.
3. Improvement in keeping quality.

The use of the butter culture is practically an application of the principle of natural selection, for the germs employed are those which have been found normally occurring in milk or cream, and which have been shown by experimental study of many species to give the finest results.

The "ripening" of cheese is a process of somewhat more complicated nature, among the many changes taking place being the transformation of casein to peptone, the formation of amido-bodies, and the disappearance of the milk sugar. Many of these changes we believe to be due to the action of bacteria or to enzymes, and the special flavor and appearance which make certain cheeses of so much value and so much sought for are the results of special methods of ripening. The bacterial changes during the process of ripening are enormous. We may have the number of bacteria increasing during the first stages from a few millions per gram to several hundred millions, and then the gradual falling off and disappearance of certain groups as the conditions become changed. Yeasts may be active in ripening some kinds of cheese, as in Swiss cheese, and moulds give the characteristic flavor to some, as in Stilton and Roquefort.

The bacteria are not all friends of the dairyman, however. Milk, cream, butter, and cheese have their "diseases," that is, defects which are brought about by various microbes. The production of red or blue milk, of soapy milk, and ropy cream, and the "puffiness" and discoloration of certain cheeses are all results of germ action, and it requires the careful investigation of the skilled bacteriologist to learn how to prevent their occurrence, and to carry on the industry with the least danger, either commercially, or from the sanitary point of view.

It should not be imagined that the bacteria which can bring about the formation of lactic acid, as in the souring of milk, are all of detriment from the commercial point of view. On the contrary, they are

often of the greatest industrial value. Two examples of their use only can here be given. Lactic acid itself is an important article of trade, as it has a wide use in industrial operations, especially in dyeing and in distilling. The acid can be manufactured far more cheaply by fermentation than by any purely chemical process — in fact, is always so produced. Some of the lactic bacteria are far more active than others, and hence a knowledge of different species or varieties enables the manufacturing chemist to produce his acid with the least waste and, consequently, the least expense. The lactic acid of commerce is made in general from corn or some grain rich in starch. This is first treated with sulphuric acid to bring about hydrolysis and then fermented, a large excess of calcium carbonate being added at the same time. By carefully controlling the temperature a very rapid change is induced through the activity of the bacteria.

The lactic fermentation finds another important application in the tanning industry, where skins of calves, sheep and goats are used for making fine leather. After the removal of the hair, the skins are put in tanks containing lime, which dissolves out certain cement substances and swells the fibers of connective tissue. The removal of the lime is necessary before the fibers will absorb tannin. Accordingly the skins are put in vats containing bran mixed with water and warmed to about the body temperature. A lively lactic fermentation ensues which causes the formation of lactate of lime, which can be washed out without difficulty.

Even the removal of the hair from skins is often accomplished by bacterial agencies. A putrefactive decay of the hair sheaths is effected, and the wool can then be easily pulled. Of the bacteria which are of use here, little is known, except that they are very active, and if allowed to act for too long a time, will produce irreparable injury to the skins. From a few personal observations I think that it is probably true also, that the liming process is in part dependent upon bacterial action, but this is an unexplored field.

The bacteria are not only of interest in dyeing operations through the lactic fermentation, but a closer application is found in the preparation of indigo. Experiment has shown that a certain bacterium is found on the leaves of the plant, and to its activity the production of the valuable coloring matter is ascribed. If the leaves are sterilized, no formation of indigo results.

Nor is bacteriology without its application to the textile industries.

In the separation of the fibers of hemp, flax, and jute, bacteria have long been employed without its being perceived that such was the case. Flax is the bast fiber of the flax plant, and in order to separate it for the manufacture of linen, it is necessary to dissolve a gummy resinous substance which binds all fibers together. This is done by a process known as *retting*. The stems are gathered in bundles and then set in tanks or rivers or ponds, where they are allowed to stay from ten to fourteen days. What actually happens is that certain bacteria present in the water multiply rapidly and bring about the decomposition of the pectin gum, thus allowing the easy separation of the fibers. The waters of certain streams are famous for their excellence in this way, as for example, the River Lys in Belgium

The food preserving industries may be mentioned as probably the most important in which a knowledge of how to combat the bacteria successfully is required. The enormous development of the canned goods industry, and the very extensive use of preserved foods of other kinds has been possible only because, wittingly or not, methods have been found for the destruction of the bacteria, or at least to prevent their action.

It is common knowledge that, unless cooked, meats and other albuminous bodies undergo putrefaction, and that starchy and sugary foods become sour. It is not because these substances are exposed to the air that they change, but because they are invaded by microbes of various kinds, and consequently are fermented. This microbial action may easily be prevented if we know the remedy and how to apply it.

The methods of food preservation which are utilized on a commercial scale are of two classes: first, antisepsis, *i.e.*, the prevention of processes of decay but not necessarily the destruction of the organisms producing it, as in cold storage, preservation with sugar, pickling, drying, and pasteurizing. The second method is sterilization, in which we stop all destructive processes by removing the cause; that is, we bring about the death of the organisms, and this finds large application in canning, *i.e.*, the enclosure in hermetically sealed packages and then subsequent sterilization by heat.

The knowledge of the behavior of the bacteria becomes a very important matter if one is engaged in any of these food industries, and lack of such knowledge has cost many business men large sums of money owing to fermentative troubles. Few people really know why sugar is a preservative in one case, and a source of trouble in another,

or why cold storage and drying are effective. The bacteriologist working with his culture tubes in all sorts of conditions explains this. He finds that cold is not as fatal to germ-life as is commonly believed, but that with low temperatures the activity of micro-organisms which produce decay is lessened, or may be suspended entirely without destroying the vitality of the germs, for if the temperature be raised again the decomposition will begin with marked energy. In a similar way the conserving action of sugar is proved to be due to osmotic changes brought about in the bacterial cells, by which the extraction of water from them results, and they are consequently rendered inert.

It is in the canning industry, however, that bacteriology is of highest importance. Here is an industry in which more than 3,000 firms are engaged in the United States, and the success of which is absolutely dependent upon the destruction of bacteria. Consider that in a single year there are packed 80–100 millions of cans of corn, and an equal number of peas, 125 millions of cans of sardines, 150 millions of cans of tomatoes, and hundreds of other foods, meats, fish, fruit and vegetables, in smaller amounts, and some idea can be gained of the importance of this industry. If all the cans of tomatoes packed in the United States during two months of 1899 were placed end to end, it would form a line more than 13,000 miles long. That is merely one of the many things preserved by canning.

As I have already hinted, lack of definite knowledge as to how sterilization should be effected, has been the source of great financial loss. This source of loss has now been largely prevented, for bacteriological investigation revealed the cause, and pointed out the remedy. It was found that in the corn there were present many spore-forming bacteria, which could withstand boiling for hours, and required heat much higher than that for their quick destruction. These bacteria attacked the sugar of the corn, fermenting it to lactic acid, and in many cases giving rise to much gas ; enough at times to burst open the cans.

Several species of these bacteria were found, some of them of great interest. Two or three species were traced to the green corn as it came from the fields, and their source thus discovered. In other kinds of spoiled canned goods, other species of bacteria were found, and in every case by study of the organisms it has been possible to provide a sure remedy against the evil.

The bacteria thus of so great commercial detriment, are of no pathogenic variety ; they are of greatest interest to the food preserver, and

in justice to the men engaged in the industry it should be said that most of the canned foods to be obtained in the markets are prepared with the greatest care, and are free from bacteria, making them of prime value as food, and without objection from a sanitary point of view.[1]

Closely connected with the food preserving industries might be mentioned the process of cane sugar refining. Here, too, the bacteria are to be reckoned with as factors of the greatest importance, since it is estimated that in some sections fully 40 per cent. of the raw sugar is inverted by bacterial enzymes and thus made uncrystallizable. If not prevented, the fermentation of the sugar may follow, giving rise to a great number of products of decomposition. Of most interest, perhaps is a change brought about by a bacterium, *Leuconostoc mesenteroides* and its allies. This organism grows but poorly when submitted to the usual treatment in the laboratory.

In solutions containing cane sugar, on the other hand, it develops with extreme rapidity, and is characterized by the formation of immense gelatinous masses of zoogloœa, sometimes of several cubic feet in size, and oftentimes completely filling the conductors and pipes of the refinery, thus entailing heavy loss. This organism is of interest, further, because of the fact that the gelatinous capsule acts as a protection to the living cell, and endows it with a certain amount of durative power so that the organism may withstand considerable periods of drying.

Recent study has shown that the number of species of bacteria which may invert or otherwise act upon raw sugar solutions is very large, and the industry is also beset with difficulties due to some extent to higher fungi, especially certain moulds.

Although less readily apparent, the rôle of the bacteria in the soil, in their relations to agriculture should be regarded as of the highest importance. Owing to the difficulties encountered in pursuing investigations in this line, our knowledge is still very imperfect, but we believe that through microbial activity the dead organic matter in the soil is transformed into mineral matter or into a form that can be utilized by green plants. Thus we get a cycle of processes taking place in the living earth. Several groups, and probably very many species of bacteria are involved in this work of breaking down matter and building it up again in new combinations. One group attacks the cellulose of dead plants, reducing it to simpler substances. Matter

[1] For a more complete account of Bacteriology in Canning Industries, see TECHNOLOGY QUARTERLY, Vol. X, No. 1, and Vol. XI, No. 1.

like urea is first hydrolized and changed into ammonium salts by another group, and the ammonium compounds are oxidized first to nitrites by the nitroso-bacteria, and still further to nitrates by the nitro-bacteria, thus completing the process of nitrification, or mineralization. The green plants then take up the nitrates, using the nitrogen in building up new protoplasmic material in the form of living cells, thus transforming the mineral matter back to organic, and completing the cycle.

Here, too, should be mentioned a group of bacteria found in the soil which enter into symbiotic relations with leguminous plants and thereby give to them the power to absorb nitrogen directly from the air. This process is known as the *fixation* of nitrogen. The bacteria enter the root hairs of the plant, increase in number, and bring about the development of nodules or tubercles. Under these conditions the bacteria become somewhat modified, some being actively motile, while others become quiescent. In a later stage the non-motile rods become branched and form a fine network known as the bacteroid tissue. When these modules are developed, the plant can take nitrogen from the air and use it in building up its own substance. This remarkable power has been found in only one or two species of plants outside the *Leguminosæ*, but practically all genera of this family can enter into this strange commensalism with bacteria, and thus these plants are characterized as nitrogen collectors, while others are nitrogen consumers. It has been suggested to utilize cultures of such organisms to enrich worn out land by inoculating the soil with them, and it is, perhaps, not too much to expect that science will turn these organisms to good account by rendering them even more productive, although the experimental stage of the process has not yet been passed.

In the foregoing pages have been imperfectly sketched some of the ways in which the bacteria have proved of use or importance in industrial operations. Others might have been mentioned. Moreover a large number of processes await investigation to prove definitely whether they are to be ascribed to bacterial causes, among them the production of silage and the curing of tobacco. Whether such changes prove to be of bacterial origin or due to enzymes produced by other organisms, there can be little doubt that the future will show many new ways in which the bacteria will be made useful to mankind.

APPLIED SCIENCE IN THE TEXTILE WORLD.

By WILLIAM W. CROSBY, S.B.

Read November 22, 1900.

WHEREVER we have accounts of the early races of man, we find that, surrounded by the forces of nature, he has endeavored to make himself the master of these forces, for he early learned that his happiness and chief good depended upon such action on his part. Where the original man depended upon the crudest of implements to till the ground by slow stages, mechanical appliances allowed him to concentrate the strength of beasts of burden upon the accomplishment of these tasks; he was enabled to provide for himself and his family some shelter other than a cave, that the fury and ravages of the stormy winds might be turned aside; he learned to make coverings for his body, adapting them to the season; but he soon found that his needs were increasing faster than his ability to supply them; for, where skins of wild beasts once sufficed for clothing, it proved cumbersome and heavy when the scorching sun shone from a cloudless sky, and the shelter that replaced the cave was not enough to protect him as it should. Just when man discovered that by interlacing small fibers material could be supplied for coverings which might be made thin or thick, and adapted to the extreme conditions under which he might find himself, is not known, but it is certain that several thousand years ago the Egyptians had developed many lines of industry in a high degree, as, for instance, spinning and weaving, making use of both form and color in their designs; for they were not content to provide alone for the comfort of the body, but also for the pleasure that might come to the eye in looking upon the design.

That most important fact which underlies the art of spinning, viz., that fibers of limited length might be made into a continuous strand by twisting them together, was a well-known principle, but for a very long time there was nothing to aid the hand in accomplishing the result. When the yarn was made and it was attempted to form the fabric, a crude loom assisted the dextrous fingers to complete the weave; true

enough, there were many beautiful fabrics, cloths of purple wrought, so it is said, with fine gold, but these were the result of the slowest kind of hand work, and of necessity were so costly as to be beyond the reach of any but the rich.

Again, we find from history that one of man's pleasures has ever been to travel abroad that he might visit with his fellow men. In the ancient days he set out with his beasts of burden, and slowly, even painfully, made his way from one place to another, with nothing to protect him from the tempest's wrath, with no means to cross streams other than fording, and arriving at his destination oftentimes so fatigued as to find little or no pleasure in the realization of his dreams. For many centuries man lived thus, although he was far from content. He mastered letters, in the fine arts he excelled, but his condition was not strikingly different from one century to another, until during the eighteenth century there came a firmer grasp upon the laws of nature, when it became evident that there must soon be an awakening, which must form the basis for an advance which hitherto had never been thought possible.

'T was well said, indeed, that "'T was ne'er entailed from sire to son; learning by study must be won;" and this is strikingly true to-day; but there is now a vastly greater field of previous successes and failures from which learning may be won. The boy in school often feels dissatisfied and chafes under the amount of work that his teacher requires of him; usually he little knows of the hours of time spent and the volume upon volume that the instructor has gone through in order that the most accurate statements may be made, that the information given may be condensed into the smallest space, and that the teaching may be as comprehensive as possible. What is attained in the present day, and that we apparently attain so much more in a given time than formerly, is due to the fact that we have learned to make these records of bygone days of more and more avail, and that we are not satisfied with learning for its own sake, but rather for what it teaches us to do in bettering our condition. When we wish to travel to-day, there awaits our pleasure a veritable palace on wheels, which defies storm and wind and rushes on over river and fen, never slackening its speed until its destination is reached. Likewise there are at our disposal an infinite variety of fabrics, machine made, and therefore at prices which all can afford, and adapted to our many wants. It is a fact that many of the attainments that have given us useful material

have not gone through any processes of inductive reasoning, but have been the result of chance: if, however, a trained mind had not been at hand to interpret, recognize, and see possibilities in the new phenomenon, in almost no case would it have developed into the reality.

The century just closed has witnessed the inception of nearly every enterprise that we now have, and that this is a fact is due chiefly to the carrying out of the principle of truth, ever and always a most lofty principle, particularly with reference to the scientific work, as mentioned before.

In this century we have had the steam engine so far perfected that we may find in a single machine the power of thousands of horses. We have the electric telegraph, which has been called one of the greatest civilizers and engines of peace the world has ever seen; more recently is given the telephone, which already enables us to talk as readily one-third of the distance across our continent as we can face to face, and there are at hand the means for indefinite extension. Our factory wheels and our street cars are moved by a waterfall, where the water has been tumbling ceaselessly and aimlessly for countless ages, waiting until the nineteenth century before it should be harnessed. Rœntgen has given the world the X-Ray, which has well-nigh revolutionized surgery, and even more, for the day has long gone by when this powerful agency has done no more than to show us the embedded bullet or the broken bone, and now opens to the physician the very inwardness of a man, showing the heart action, lung diseases and the like, as clearly as if printed upon the open page.

It is not to be wondered at that Keeley, with invisible capillary tubes, charged with highly compressed air, could impose upon a long-suffering public; nor, again, that another man could float a company which proposed to make ten electric lights burn where but a single one glowed before; nor that a Jernegan should obtain thousands of dollars belonging to other people presumably to organize a company which might extract gold from sea water, — not quite so preposterous, to be sure, as extracting sunbeams from cucumbers. There was an element of truth, however, for does not even the embryo chemist know that there are gold and silver in sea water, and does he not know that it is found in very small quantities and that some natural facility must be afforded to handle larger quantities of water at the lowest cost, if the thing is to be made practical? When Jernegan established his plant on the far-away coast of Maine he took account of all these things,

for there the tides rise high and flow swiftly. The water that might be treated at one ebb and flow would be carried far away and a fresh lot brought to hand for treatment, by nature's own forces. Here was a case where even scientific credulity was imposed upon, although by a sufficiently careful analysis it could most surely have been shown that the operation was at fault.

All this goes to show that the human family does pay deference to the productions of modern science and is ever ready to receive and appropriate new truths as they are promulgated. There must of necessity be some bad mixed with the good, some bitter with the sweet.

An historical review of scientific attainments of bygone days shows that many phenomena were observed and many individual investigations made, but each was distinct by itself and had little or no connection with others. They added little, if anything, to the happiness or advancement of the human family, so that when they did become, in later days, of some importance, and when there appeared a particular connection between themselves and the daily affairs of men, they were discredited. In other words, there came to be drawn a very strong line dividing theory and practice.

At the present time this barrier is fast sinking. In nearly every case where we hear it said that theory and practice do not agree, we can find by investigation where the theory was wrong or incomplete, usually the latter, or where the practice was imperfect.

There never was a time in the world's history when advancement along all lines of manufacture has greater impetus than now. We have striking illustrations of the relations between manufacturing countries where trained skill is employed and those where it is lacking. It is shown that, within the United States, those States that do most for education have the highest productive capacity. With an average duration of school attendance in a recent year of 4.4 years for the United States at large, Massachusetts showed seven years and Tennessee but three years. The productive capacity of the United States at the same period was 55 cents per day, Massachusetts 85 cents, and Tennessee 38 cents. The expenditures were, for the United States, $2.67 *per capita* of population ; in Massachusetts, $5.07, and in Tennessee, 83 cents. This is not an isolated case, although it is a very strong one, and its lesson is obvious.

We have seen in our own country a most phenomenal growth in

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the iron and steel trade. Why have we been able to build bridges in a shorter time and at a less cost, to be erected in a far-away continent, where all the mechanical appliances to be used in their erection might be had only by taking them there, where men used to our climate have worked under tropical suns and under the most adverse conditions, and then have received the well-merited applause of the whole world? Why have we been enabled to build locomotives, adapting them to the particular conditions of countries all over the earth, and to place our products in competition with the world? Why have we made tons upon tons of water wipe to send to Australia? Why are there many representatives from the far-away "Yankee land of the East" in our country to buy looms? Again let me ask, why have we been able to do these things within the last decade and not before? Surely not because the iron ore was not in the mountains, nor for the lack of coal, nor yet for the lack of capital. There can be but one answer. Because we did not know how.

From time immemorial the man who has mastered letters has been universally looked up to as the possessor of something occult, that he was far above those who had not his attainments. Those professions that depended upon such a knowledge were accordingly placed on a high pedestal long ago, while he who shod your horse and mended the tire on your wagon was looked upon as one possessing a trade, which was to be attained only by the repetition of those selfsame operations. To be sure, the man of letters could have learned those operations, and doubtless they would have been learned very well; but the step from the blacksmith's anvil to the great hammers weighing many tons, which now forge the frames for a multitude of new machines, the field rings which make possible the gigantic generators at Niagara, the armor plates which protect our battleships, and the shafts which drive these ships from ocean to ocean, would never have been possible if something other than manual dexterity had not been acquired.

It was not often that the apprentice ever exceeded his master in skill, and if he did it was in some trifling detail, if he depended upon his hands alone. When once it was realized that the advancement in any line was attained, not by a great manual dexterity, but by an application of the mind through the hand, then we had the inception of scientific schools.

Without doubt the high position of our own country in the affairs of the world along the lines just spoken of may be ascribed to the

training that we have had through these scientific schools. There is one school which dates back to about the first quarter of the last century, but those that are now the largest and best known date back to within only the last half century — far enough back, however, so that the graduates may take important positions in the manufacturing and mercantile enterprises which are so far in the lead of our great prosperity.

The growth that is of the most importance is the one whose roots have sunk deep enough to supply in the dryest time the trunk and branches with the needed nourishment, where the minimum flow must never be less than such an amount as will satisfy the demands of the whole. Such a growth is of necessity slow, and usually the slower the growth, the firmer will be the substance, well fitted to withstand the storms and ravages of time.

The centuries have been accumulating a fund of knowledge, which is now in our hands; it has led us to the position where we can advance much more rapidly than of yore, each success making way for many new and useful things. Suppose the carpenter to be building for you a house; nowadays he selects for his stock the frames, boards planed and finished, mouldings, floorings, doors and window frames, where once he was fortunate to obtain the lumber roughly squared and dry enough to work. What is the result? Does the carpenter know less, or are these various specialists mere machines of parts of their machines? Does it throw out of employment the high-priced man who could perform all these operations? No; rather it opens up countless other positions in allied industries, giving in almost every case employment to a far greater number of men, and with the added advantage that the product may be within the reach of a vastly larger number of people, whose homes may be beautified, or made comfortable, or both. Who a hundred years ago ever heard of a motorman? Or what would our forefathers understand by such terms as conductor, lineman, stoker, brakeman, bacteriologist, analyst, or, indeed, a score of others?

Each specialization brings a new field with its many positions into view, and adds rather than cuts down the number of available opportunities where men may work. To be sure, many improved machines do away with an amount of manual labor, but require more and better skilled labor at the head of the line. The law of the survival of the fittest must ever dominate.

In seeking to surpass previous attainments, man long ago had provided well for the necessities of life, and not much was lacking to make

him comfortable, but he was not satisfied with this; he launched out in all directions; he would have fruits from the tropics, spices from the East, tea, coffee, and, in fine, everything to be had in the world, and would exchange for them his own products. He must have ready and efficient means for communication, that he might travel and visit wherever he chose. He was not satisfied to clothe himself with that which would make his body merely comfortable; he sought to adorn it, and the coverings of the walls and floors of his house have been treated similarly.

There is no more striking mark of the advance of civilization of a people than the degree of beauty in their structures,—this term being used in the broadest sense, comprising whatever must be put together for some particular use, but is nevertheless susceptible to adornment,—and this is especially apparent in the textile fabrics.

There is no department among the industries of the world where there has been a greater lack of well-trained minds than in producing the countless varieties of fabrics with which we clothe ourselves and beautify our homes. To be sure, it is not so very long a time since there was nothing but the crudest form of hand machine to clean the fiber, make the yarn, or weave the cloth; and until the cloth itself could be constructed there was obviously no chance to even attempt to beautify.

The tapestries of the olden time and the fabrics with their intricate designs were made by the slowest process of hand work, and were therefore so costly as to be beyond the reach of the masses. When power machinery was introduced, the quantity of the output was increased, a uniformity of product secured, and a great reduction in price made, although none but the plainest of goods was produced. This was the first great step forward, but in a work on cotton manufacture, published no longer ago than 1836, it is stated that "the plain loom is running well, and great hopes are entertained that there will soon be a power loom for weaving fancy goods." There have been great difficulties for the manufacturer to overcome, and there has been, accordingly, the greatest tendency for him to continue with a given line of goods, so long as a market could be found, changing only when necessary to keep up the trade.

The apprentice system was good, and it turned out men who managed these enterprises in a masterly way, but who shall say that it might not have been better? It is not in the power of every one to

impart knowledge, and the young man who depends entirely upon his own quickness of perception, and what he may acquire by chance from others, is most surely handicapped in the race with the elements, as compared with him whose mind is directed by those selected for their capability and skill in whatever line it may be. There is not a lack of properly developed artistic ability to blend form and color in perfect harmony; this has been in the world for centuries. It is the *mechanical means* to reproduce these things that has been lacking. Who can estimate the uplifting influence of the numerous photographic, lithographic, and other printing processes in scattering broadcast, and bringing within the reach of the poorest, the best art in the world? While this may have its effect upon civilization, people are not compelled to look at such things, as they are compelled to look upon their clothes, carpets, and hangings, which contribute primarily to their comfort, and yet have been well-nigh hideous to the sight. Here we meet the serious question of mechanical devices to further our ends.

Wonderful results have been obtained, but the field is wide for conquest. Even now many processes are crude, but the means for study and investigation are increasing fast.

Foreign countries are far ahead of us. Germany in particular has a most elaborate system of schools in direct touch with nearly every department of industry, and is, accordingly, occupying an enviable position with relation to the world's affairs, though according to our standards their schools are chiefly trade schools.

A piece of plain fabric, long a standard product of our mills, is worth, as raw stock, some eight or nine cents per pound, and only eighteen cents per pound as print cloth; to this additional nine or ten cents are charged the pay roll, repairs, taxes, insurance, depreciation, waste, and a very small profit. A bit of Swiss muslin is worth but little more in the raw stock, yet with the same pound of cotton in twenty yards of fabric will sell for $8 or $10. Is it not time that we were alive to the situation?

In developing the higher grade of goods, particularly with color added, we must take advantage of almost all the research of modern science; at least, we must appropriate something from every department, for the degree of precision attained demands an application of skill in a continuously increasing quantity.

The question of trade schools and of how far science may be applied to art without losing its identity has been long a subject of discussion.

It needs no extended argument to prove the value of the application of the principles of pure science to the production of tangible results.

The gap between pure science, particularly in mathematics and physics, on the one hand, and applied science on the other, has been in many cases as great as between science in general and the so-called practical part of the world; and it is even amusing to a disinterested spectator to note the apparent astonishment on the part of certain speculative mathematicians, whose great delight is in the 4th, 5th or *nth* dimensions of space, when they are shown tangible results that can be laid off and measured with a foot rule, emanating from many-fold integrals.

If we admit that material progress is dependent upon a perfectly secure footing in the principles of science, we must not leave any stone unturned until these fundamentals shall be as surely established as is the rock of Gibraltar. One man or set of men must enunciate and substantiate the purely theoretical part of the work, and another must take up so much of that as may be necessary to the completion of their ends, for it is obvious that no one man can live long enough to dominate both fields. While not discrediting the trade school, so called in the strictest sense of the word, one should look with some suspicion upon it, if it does not make use of the latest and best methods of science, — not depending upon the result alone, but inquiring carefully into the correctness and reliability of all the elements. It is not enough in many cases to give a man a general training which will enable him to understand the deductions of the purely theoretical side, leaving him to find an application for himself. True, there will always be a demand for a large number of these men, but there will be an equally great, if not greater, demand and for a larger number of men who are one step further removed from the purely theoretical side, and at the same time are more strictly in touch with the material or result-yielding portion of the community.

There is invested in the State of Massachusetts in the textile industry about one hundred and sixty-seven million dollars. While there is a question in the minds of some as to whether the cotton industry will survive the competition of the South, there surely is not any need to fear a very immediate removal. There are certain features of the case which will eventually change, so that the question of labor, taxes, insurance, and others closely allied, will doubtless soon settle themselves. With all this capital invested, it can safely be taken for granted that if we cannot make the coarser grade of goods, we will make the finer. It

is, then, no wonder that hitherto the large proportion of our cotton crop should be sent abroad, manufactured into the finest goods, sent back here and sold over the counters of our stores; for we have not been providing the means to properly train our own people, who should have been employed in manufacturing these goods, while across the water every possible means has been brought forth. Long ago we found ourselves solving well some kindred questions. More recently we have taken up the problem of the application of science to the textile world, and we find that the further we travel, the higher we climb, just so fast does the horizon, which seems to mark the limit of attainments, recede.

The leading manufacturers of Lowell long ago realized the necessity for meeting this problem, and after much study organized as the Trustees of the Lowell Textile School. In this school they have collected such machines as are in use in the production of the fabrics of the present day, and have assembled a corps of instructors who are entirely familiar with the practical running of these machines, and at the same time, so far as possible, are thoroughly well grounded in the theoretical side of their several branches. It was seen early that such a school must, first of all, produce as good results as were attained in the best mills, and when this point was attained, all the research of modern science must be brought to bear if any advance was to be made. The work soon developed into the laboratory method, the instructor first covering the ground by a lecture, and afterward causing the student to produce the tangible result upon the machine. When it is realized that at the present time almost endless numbers of effects in the finished goods are produced by combinations of fibers, chemical changes, etc., it is not hard to see how extensive an equipment is necessary to handle such work.

The school already has complete equipments for producing the different varieties of cotton, woolen, worsted and other yarns, making the designs, ornamentations, and harmonizing the colors for the fabrics, weaving the same, as well as handling the chemistry and dyeing which may be necessarily connected therewith. The school has been in operation a sufficiently long time to observe the results attained to some extent, and it is found that these results have been good; for everywhere the manufacturer is realizing, as never before, that he must have trained skill in and about his mill; and on the other hand, it is seen that science alone is of small avail if it be not applied.

BOOK REVIEW.

ELECTRICAL TESTING.[1]

As a result of the rapid development of the profession of Electrical Engineering and the consequent necessity of giving an adequate experimental treatment of the various branches of the subject, the demands on the time of the student have become most exacting. This forces one to consider most carefully the general arrangement of laboratory work and the particular experiments which should form the course. As it appears to us, the subject of Electrical Testing should be one that not only furnishes the student with certain tools of trade, but should possess a real educational value in establishing a critical attitude of mind in respect to all experimental work. Therefore only the best methods should be included in the course, and these should be accompanied by a suggestive text in which possible sources of error are adequately discussed. It is with these things in mind that we turn to the recent volume by Professor Parr.

The sub-title, "A Course Suitable for First and Second Year Students and Others," explains in a measure the nature of the experiments included in the book, and the statement that the volume is to be followed by another which will treat of experimental work of a character more intimately connected with electrical engineering, may be taken as an explanation why certain things are omitted.

The book is divided into four parts. The first is a laboratory manual of 215 pages devoted to direct current measurements, including properties of iron and measurement of inductance. In this section the subject matter is divided into 120 sections, nearly every one of which treats of a distinct experimental method. Following this is an appendix of 30 pages in which demonstrations of the various formulæ occurring in the first part are to be found. A section of 101 pages treats of apparatus, and is illustrated by cuts of instruments by

[1] **Practical Electrical Testing in Physics and Electrical Engineering.** By G. D. Aspinall Parr. **New York**: Longmans, Green & Co. 392 p., 231 ill. $2.50.

well known makers, as well as those in the laboratory of the author. The concluding pages are occupied by Tables of Constants, Logarithms, Trigonometrical Functions, Squares, Reciprocals, Doubled Square Roots, and an Index.

Each experimental section is subdivided as follows: An introduction containing in a condensed form the theoretical consideration on which the experiment is based. A statement of the apparatus required. Instructions as to carrying out the observation, and in some cases specific questions on the preceding work.

On opening the book one finds that the first section is on Curve Plotting, but the capabilities of the Graphical Method for determining the constants in particular forms of equations are not referred to. Another noticeable omission is that of all precision discussions, as well as those pertaining to best arrangements of apparatus. Also no adequate treatment of possible sources of error in the various experiments is given.

The elementary nature of the earlier experiments is probably explained by the fact that the book is for the use of first year students; but it seems to us that a number of them might with profit be omitted, especially if the student has had previous training in manipulation. For instance, there are four methods of measuring galvanometer resistance; eight methods for battery resistance; and nine methods of comparing E. M. F's. We understand that the book is not a compendium of methods, but a laboratory manual, and as such the methods presented to the students should be those of approved value.

The instructions for the experimental work are so specific that much of the educational value of the laboratory training is lost. A notable omission is that of all calibration work, one of the most important branches of Electrical Testing.

In view of the foregoing, our chief criticism of this laboratory manual is that it fails to embody those results of criticism and of personal experience which contribute so much to the training of the student and qualify him to attack new problems in the most advantageous manner.

FRANK A. LAWS.

TECHNOLOGY QUARTERLY

AND

PROCEEDINGS OF THE SOCIETY OF ARTS.

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PROCEEDINGS OF THE SOCIETY OF ARTS.

THIRTY-NINTH YEAR, 1900–1901.

BOSTON, April 11, 1901.

THE 552d regular meeting of the SOCIETY OF ARTS was held on this day at 8 P.M. at the Rogers Building, President Pritchett presiding. Fifty persons were present.

The following candidates were elected to Associate Membership: Messrs. John S. Eynon, C. E. Sherman, and Joseph C. Riley.

Dr. George W. Field, Biologist to the Rhode Island Agricultural Experiment Station and Lecturer on Economic Zoölogy at the Institute, spoke on "The Increase of the Food Supply of Mankind through the Cultivation of Marine Animals: a Problem in Economic Zoölogy."

"The shore and deep sea fisheries were the economic foundation of human existence in New England. The numerous shell heaps along the coast testify to the importance of the shellfish to the Indians; the chronicles of that first winter on Plymouth shores tell how the Pilgrims 'sucked the abundance of the sea.' The settlers of Boston and the North Shore laid the foundations of prosperity in salt codfish for export trade.

"Massachusetts is well-nigh alone in her fortunate aquatic geographical situation, being at the meeting line of the cold northern

waters remarkable for the small number of species but enormous numbers of individuals, *e. g.*, cod, herring, lobster, oyster, clams, scallops, etc, and the warm tropical waters remarkable for the untold multitude of different species but with a relatively small number of individuals of each species.

"The physiographic features of Massachusetts likewise made for great productiveness; the indented coast, with shallow bays, and numerous rivers cause a rapid growth of marine vegetation, which becomes the pasture for enormous quantities of marine animals, which, in turn, become food for man. This change of inorganic substance washed from the land into plant and animal substance is rapid on our shores, and the productive capacity of any area is dependent upon the rate of change, just as a business enterprise may prosper according to the rapidity with which the capital is turned over.

"Aquatic plant and animal life falls into two groups: the stationary, fixed to the bottom, and the freely wandering, the Plankton. The Plankton is the more valuable for producing crops of food animals, and a study of the Plankton permits a forecast of the prospective and actual economic value of any given area of water.

"Water under favorable conditions produces a greater quantity of nitrogenous food material than an equal area of land. Water is as amenable to cultivation as land, and conditions are practically duplicated. The same conditions which have led to the necessity of cultivating the land are beginning to call urgently for the cultivation of the water. Increasing population results in increased demand, soon exceeding the supply. Unless the supply be augmented, we draw on nature's capital, and biological bankruptcy is sure to follow. The destruction of adult animals by man results in upsetting nature's equilibrium, and upon man comes the responsibility for making the proper adjustments. Civilization continuously restricts the areas available for marine animals. Human cupidity and lack of foresight lead to improper laws. 'That the products of the sea belong to the people as a common heritage guaranteed by the constitution' is narrowly interpreted in the interest of those who catch or sell the products, and against the interests of 'all the people' who are dependent upon the products of both land and sea for reducing the cost of living. The public, through the machinery of the state, has decided upon its relations to the ownership of lands and their products; similar decisions must be made in regard to water areas. This

is especially important for the clam industry of New England. Uniformity in biological legislation for sections which have the same biological conditions is feasible and necessary. Steps should be taken to make uniform laws in New England in regard to the lobster, clam, oyster, scallop, game, fish, birds, injurious insects, and infectious plant diseases.

"Public biological museums should be located in every city, especially conducted for giving reliable information upon all economic questions in regard to plants and animals. Each collection should at first deal only with the species and conditions found in that immediate vicinity. In this way a reasonable degree of completeness might soon be obtained.

"The problems immediately connected with the supply of lobsters are numerous, important, and difficult of solution. The aggressiveness of the lobster, young and adult, precludes sociability, and therefore the number which can live in a given area is strictly limited. The natural breeding ground, too, of the species is comparatively restricted; it is bounded on the north by the icy waters of the Strait of Belle Isle, between Newfoundland and Labrador, while the most southern point where stragglers have been taken is the coast of North Carolina, an area approximately 1,300 miles long and thirty to fifty miles wide, or about 50,000 square miles. The coast of New England should produce the greatest number of marketable lobsters, since it is at about the middle of the range.

"In spite of assertions to the contrary, it would seem that the following figures, compiled from the returns to the Massachusetts Commissioners of Inland Fisheries and Game, indicate conclusively that there has been a steady and rapid decrease in the lobster supply. Of the nine years for which returns of Massachusetts are available for study, three show an increase in the number of lobsters caught; but, unfortunately, this is the result of a larger increase in the number of men and traps employed, while the other six years show a decrease in all points.

"The figures are from 1893 to 1900, inclusive:

	Number of men employed.	Number of traps.	Adult lobsters.	Egg-bearing lobsters reported.
Total increase in 1894, 1896, 1900, over the preceding year.	110	8,027	40,867	2,156
Total decrease in other six years.	193	11,053	544,100	19,259
Net decrease in last nine years.	83	3,026	504,233	17,103

Or net decrease given in percentages:

In number of men employed,	21.2%
In number of traps used,	17.7%
In number of large lobsters taken,	43.9%
In number of egg-bearing lobsters reported,	52.2%

"This shows that there is a smaller net decrease in the number of men; that these men are compelled to use a greater number of traps per man on the average, and that the number of lobsters above 10½ inches has decreased very markedly (by nearly one-half), while the number of egg-bearing lobsters reported has diminished more than one-half.

"The main cause of the decrease is the increased demand, leading to the destruction of the sexually mature adults; an increased demand which has not been met by a corresponding increase in the supply. The demand has been stimulated by the gastronomic devices, but the source of supply has received little popular attention beyond the short-sighted policy of catching as many lobsters as possible.

"Ultimately man must assume the same relations to the lobster and fishing industries as has come about with domesticated animals and plants. Thus far no satisfactory method has been devised for domesticating and propagating the lobster; the necessity for it is only beginning to be urgent. The method of life, the seasonal immigrations from deep to shallow water, the slow rate of development and growth, and, above all, the combativeness and cannibalism of the old and young, all unite to make the problem of artificial cultivation difficult to handle, though by no means hopeless in the present state of our knowledge. The great need is for study, correlation, and interpretation upon methods of rearing the young and of catching lobsters of the size best adapted for the market, with special reference to maintaining and increasing the supply."

The thanks of the Society were most heartily extended to Dr. Field for his able paper.

BOSTON, April 25, 1901.

The 553d regular meeting of the SOCIETY OF ARTS was held on this day at 8 P.M., Room 11, Rogers Building, Professor Peabody presiding. One hundred persons were present.

The report of previous meeting was approved. The Chairman appointed Mr. Leach, Dr. Walker, and Professors Peabody, Bartlett,

and Laws to serve on a committee to nominate the Executive Committee for the year 1901–1902. Messrs. William A. Hovey and W. O. Sawtelle were elected to Associate Membership.

Professor J. E. Denton, Stevens Institute of Technology, gave a very instructive address on "Principles of Action of Various Types of Refrigerating Machines."

BOSTON, May 16, 1901.

The 39th Annual Meeting (the 554th regular meeting) of the SOCIETY OF ARTS was held at the Institute on this day at 8 P.M., with President Pritchett in the chair. Fifty-six persons were present.

The records of the previous meeting were read and approved. The Secretary read the Annual Report of the Executive Committee. It was voted that the report be accepted and placed on file.

ANNUAL REPORT OF THE EXECUTIVE COMMITTEE.

The first meeting of the SOCIETY OF ARTS for the present year was held on October 11, 1900. Fourteen meetings have been held, the average attendance being 143. This shows a considerable gain over last year.

The following papers have been read:

"Color Photography," by Professor Louis Derr.

"Some Experiments in Architectural Acoustics," by Professor Wallace C. Sabine.

"America's Contribution to Our Knowledge of the Size and Figure of the Earth," by Dr. Henry S. Pritchett, President of the Institute of Technology.

"Applied Science in the Textile World," by Professor W. W. Crosby.

"Landscape Architecture in This Country," by Mr. Guy Lowell.

"Shipment of Freights to Europe," by Mr. William H. Lincoln.

"Photography with the Great Visual Telescope of the Yerkes Observatory," by Professor George E. Hale.

"The Designing of the Buffalo Exposition," by Mr. Robert S. Peabody.

"A Forest Policy for the United States," by Mr. Gifford Pinchot.

"The Use of the Microscope in the Study of the Chemical Constitution and Physical Properties of Metals," by Dr. Henry Fay.

"Electrical Wave-Transmission," by Professor M. I. Pupin.

"The Increase of the Food Supply of Mankind through the Cultivation of Marine Animals: a Problem in Economic Zoölogy," by Dr. George W. Field.

"Principles of Action of Various Types of Refrigerating Machines," by Professor J. E. Denton.

"Cotton from Seed to Bale," by Mr. Henry G. Kittredge.

At the beginning of the year the Associate Membership was 339. Of this number one has died, nine resigned; twenty-five have, however, been elected, making the present membership 354.

During the year the Society has suffered the loss of one of its oldest members, Mr. Thomas Gaffield, who served on the Executive Committee from 1879 to 1883. Mr. Gaffield's interests were not confined to the welfare of the SOCIETY OF ARTS alone, but also

to the Institute, as evinced by his gift of books, specimens of glass and minerals to the Departments of Geology and Chemistry. At the time of his death he was a member of the Corporation of the Institute.

No change has occurred in the management of the TECHNOLOGY QUARTERLY. Since the last Annual Report twenty-five articles have been published. Probably the most notable of these is one on the "Eclipse Expedition of the Massachusetts Institute of Technology to Washington, Georgia, under the direction of Professor Alfred E. Burton." Illustrating this article is an excellent photogravure reproduction of one of the best photographs of the sun's corona that has ever been taken. This article has been followed by one from the Rev. Professor William F. Rigge, S. J., who also observed the eclipse at Washington, Georgia, being in charge of a party from Creighton University, Nebraska. In this paper Professor Rigge makes an interesting comparison between his results and those obtained by the party from the Institute, all of which redounds to the credit of both parties. Professor W. O. Crosby has contributed two articles giving the results of his explorations of the sites of proposed water supplies for New York and Brooklyn. A gratifying instance of the loyalty of our alumni is furnished by the frequency of the contributions of two graduates of the Institute, Messrs. George C. Whipple and Daniel D. Jackson. They are actively engaged in investigation of problems connected with the biology and physical characters of the water supplied to towns, and have contributed four articles on different branches of this subject. Among other articles from the Physical Department are a series of tests, made by Professor Norton, on Fire Retardent Materials, and a series on Diffusing Glass of various kinds used in windows; and from Mr. William Lincoln Smith an extensive series of tests of Certain Shades and Globes for Electric Lights as used in Interior Illumination. From the Mechanical Engineering Department the usual annual contribution of Tests Made in the Engineering Laboratories was published in the September issue. Professor Fay and Mr. Badlam contributed an important article on the "Effect of Annealing upon the Physical Properties and the Microstructure of a Low Carbon Steel;" and the "Review of American Chemical Research," contributed by a number of members of the Chemical Department, has appeared regularly in each issue. Beginning with the current volume, a change has been made in the paper used in printing the QUARTERLY, and it is hoped that some saving of expense will result.

Respectfully submitted,

(Signed) GEORGE W. BLODGETT.
EDMUND H. HEWINS.
CHARLES T. MAIN.
JAMES P. MUNROE.

The Secretary read a communication from the Committee on Nominations, in which the following gentlemen were named as candidates for the Executive Committee for the year 1901–1902: George W. Blodgett, Desmond FitzGerald, Edmund H. Hewins, Charles T. Main, James P. Munroe. Mr. Blodgett announced that the Executive Committee had nominated George V. Wendell to be candidate for the office of Secretary.

A ballot having been taken, the Chairman announced the election of the above-named candidates.

Mr. Henry G. Kittredge, Industrial Editor of the *New York Commercial*, was introduced and gave an illustrated lecture on "Cotton from Seed to Bale."

"Thus far the Southern States of the United States have shown themselves to be the most extensive region and the best adapted for the growth of cotton of any in the world. No country has such an excellent river system and climate for the growth of this staple in its highest state of perfection. The cotton area of the Southern States is about 400,000 square miles, or about 250,000,000 acres, of which about 25,000,000 acres are now devoted to the cotton plant. This is at the rate of one acre in every ten. Rather than to increase this acreage, it would seemingly be better to intensify the culture of cotton by means of fertilizers for a larger yield. The meteorological conditions of the South must be taken as the standard for the world for the cultivation of cotton. The average temperature of the Southern States during the cotton-growing season is about 75°, while the relative humidity during this period ranges from 65° to 80°, and the rainfall amounts to 48 to 50 inches in the course of the year, with the dryest period during the growth of the plant. In order to secure the best results for length of staple, fineness of fibre and yield, great care must be taken in the proper selection of seed for planting and great care exercised in cultivation. More attention is given to the selection of seed in the planting of sea-island than in the upland varieties of cotton, though increased attention has been given to the latter in recent years. The system of cultivation varies in different parts of the South, depending upon the character of the soil and drainage. Among the diseases that affect the plant none has shown so much obstinacy as that known as the 'wilt.' This disease is not thoroughly understood, and no universal remedy is known for its complete eradication. It would seem to arise from the soil, where it lingers for a number of years. Hybridization is important in bringing cotton to a proper standard, which, after being attained, can be held only by careful selection of the seed for propagation."

The thanks of the Society were most heartily given to Mr. Kittredge for his instructive address.

GEORGE V. WENDELL, *Secretary.*

GEOLOGICAL HISTORY OF THE HEMATITE IRON ORES OF THE ANTWERP AND FOWLER BELT IN NEW YORK.

By W. O. CROSBY.

THE occurrence in specimens of the massive red hematite from the old Sterling iron mine near Antwerp, in Jefferson County, New York, of more or less pyrite and possibly pyrrhotite, in addition to the well-known pockets lined with crystallized siderite, chalcodite, specular hematite, and quartz, and further adorned by the brilliant golden needles of millerite for which this mine is famous, long ago suggested to me, as, perhaps, to others, that the hematite has had its origin in the differential oxidation of slightly nickeliferous iron sulphides, the nickel having remained in combination with the sulphur and recrystallized as millerite. But when in the summer of 1895 I visited the Sterling Mine, in company with Captain Hodge, an intelligent resident of Antwerp and for many years superintendent of the mine, and a party of students, I was surprised, not having previously read up on the geology of the mine, to find that the ore occurs in, and in intimate association with, a massive, soft, greenish-black, chloritic-looking rock, which is divided in all directions by slickensides and appears to be a highly altered (chloritized) trap. This rock was called serpentine by Ebenezer Emmons.[1] In part it bears some resemblance to serpentine, but in general the aspect is chloritic rather than serpentinic. Being fresh from the study of the deposits of nickeliferous pyrrhotite and chalcopyrite in the dioritic rocks of the Sudbury district in Ontario, and of the Gap Mine in Lancaster County, Pennsylvania, which had been quite clearly shown by Kemp and others to be products of magmatic differentiation, I at once adopted this as a provisional explanation, or working hypothesis, for the deposits of the Sterling Mine, and probably of the

[1] Geology Second District, pp. 93–96.

other mines of the Antwerp-Fowler belt, Captain Hodge having assured me that the geological conditions were similar throughout this linear series of deposits.

At the time of my visit, all of these mines had been closed for some time, probably never to be reopened; but my observations on the surface, including the dumps, supplemented by such information concerning the underground conditions as the superintendent could give me, led me to the conclusion: that the ore-body of the Sterling Mine is in a dike, 50 feet or more in width, of some highly altered basic rock, possibly diabase; that the ore was originally a magmatic segregation of this rock, chiefly in the form of sulphides, which have subsequently suffered more or less complete oxidation to a considerable depth, the ore being now, virtually, a gossan; and that this dike is, probably, continuous for the entire length of the belt of mines, although absolute continuity is by no means essential to the hypothesis.

The trend of the ore-belt and the hypothetical dike is approximately northeast from the vicinity of Antwerp, closely following the valley of a tributary of the Oswegatchie River. At the Sterling Mine, two and one-half miles from Antwerp, the southeast side of the valley is gneissoid granite, and the northwest side is Archæan limestone. The granite is of a distinctly acid type, of a light gray color and medium texture, rich in quartz and decidedly poor in ferromagnesian minerals — chiefly biotite; but with slight pegmatitic developments of only moderate coarseness. The granite appears to form the southeast wall of the dike, and the limestone, in a general way, the northwest wall, except that in the immediate vicinity of the mine the dike is, superficially, bordered on the northwest side by an outlier, probably of no great thickness, of the Potsdam sandstone. The descriptions of the mines by Putnam, in the *Tenth Census Report* (Vol. XV, pp. 141–144), indicate that the sandstone is a fairly constant feature of the deposits, occurring also at the Shirtleff Mine in the town of Philadelphia, which is not in the trend of the Antwerp-Fowler belt, and probably represents a distinct dike or occurrence of the chloritic rock and its associated ore. In most cases, however, the sandstone, which is still approximately horizontal, is described as covering the chloritic rock and ore more or less completely, suggesting that this basic igneous rock may antedate the sandstone, which was spread by the Potsdam sea across its outcrop; and certainly

the extreme alteration of the chloritic rock is indicative of a high antiquity. But, on the other hand, I have observed nothing in the composition of the sandstone as developed at the Sterling Mine confirmatory of the view that it was deposited over the ore-bearing formation. It is equally true, however, that it contains little or no identifiable detritus from the Archæan granite, for it is the clean, white, quartzose sandstone of fine and even texture so characteristic of the base of the Potsdam; and its composition harmonizes readily with the hypothesis that it is the newest rock in the section, as indicated by its horizontal attitude, if we accept the view developed in my study of the Archæan-Cambrian contact in Colorado,[1] that the transgression of the Potsdam sea over this area was so slow and gradual that erosion had time to accomplish its perfect work, base-leveling the surface and reducing all detritus to the two final terms — fine quartz sand and clay. Under these conditions sediments will rarely reflect in any reliable manner the mineralogical character of formations which they cover unconformably.

Unquestionably, the interest of the geology of the Antwerp-Fowler mines centres in the nature and origin of the chloritic rock and its true relations to the ores. On returning to Boston with my collection, I found that in the previous year (1894) Professor C. H. Smyth[2] had expressed the opinion, based upon microscopic and chemical examinations, that the chloritic rock is a highly altered phase of the granite. The fact upon which he especially relies is the occurrence in the chloritic rock of glassy grains and masses of quartz, which are regarded as residual. His analysis of a specimen free from visible quartz shows: SiO_2, 30 per cent.; MgO, 11 per cent.; FeO, 27 per cent.; and H_2O, 12 per cent.; the remaining 20 per cent. being, presumably, chiefly Al_2O_3. This is approximately the composition of prochlorite, and indicates an ultra-basic rock; while the granite, as represented by my specimens, is rich in quartz and poor in ferro-magnesian constituents, and certainly contains as much as 70, if not 75, per cent. of silica.

The general aspect of the rock is precisely that of many highly chloritized traps in the vicinity of Boston; and this resemblance is heightened by the slickensides, by which it is minutely and almost

[1] Bull. Geol. Soc. Amer., 10, 141–164.

[2] Bull. Geol. Soc. Amer., 6, 4.

indefinitely subdivided (Figure 1). These testify to differential movement throughout the mass, and can have, apparently, but one explanation — expansion due to chloritization and hydration. It is manifestly impossible to find in this light-colored, acid granite more than a small fraction of the magnesia and ferrous oxide shown by Professor Smyth's analysis of the chloritic rock. They are clearly not chiefly residual constituents of the granite; and if his hypothesis stands, the main

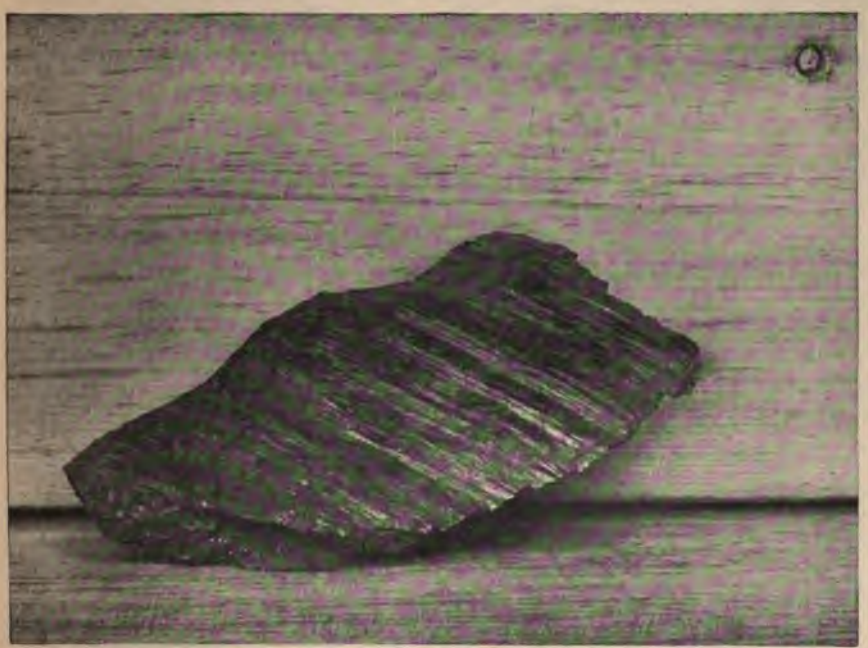

FIG. 1. — A fragment of the chloritic rock, showing slickensides. Two-thirds natural size.

part of each must be imported. The only alternative is to suppose that the silica and alumina have suffered a highly improbable diminution, in which case the expansion of the rock essential to the explanation of the slickensides would be unexplained. But where can we find an adequate external source of the MgO and FeO? Professor Smyth suggests the Archæan limestone and the action upon it of solutions derived from the oxidation of some near-by deposit of pyrite. But no sulphides are known in the vicinity, except those intimately associated with the hematite in the chloritic rock; and it is not apparent by what reactions the magnesia of the limestone, existing,

probably, largely in the form of insoluble silicates, is to replace the acid aluminous silicates of the granite, reducing the silica by fully 40 per cent. Professor Smyth seems, further, to regard the ore as a replacement of limestone, although so intimately associated with and enclosed in the massive chloritic rock, which is interpreted as an altered phase of the granite. The masses of crystalline calcite in

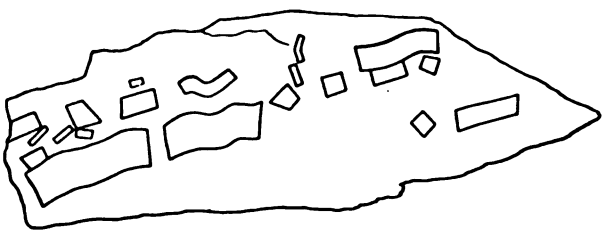

FIG. 2. — A fragment of the chloritic rock showing, diagrammatically, stretched and dislocated veinlets of quartz. One-third natural size.

the ore are certainly suggestive of inclusions of limestone; but it is important to remember that calcite is an exceedingly common secondary mineral of the basic eruptives, as witness the crystalline calcites of the cupriferous melaphyrs of Keweenaw Point.

Apparently, the chemical difficulties of Professor Smyth's thesis are insuperable; but we turn now to the consideration of his main argument — the disseminated grains of quartz in the chloritic rock. To begin with, the free silica or quartz appears to be wholly or almost wholly wanting in a considerable portion of the chloritic rock; and it is probably this material that is represented by Professor Smyth's analysis. A considerable part of the quartz, also, occurs, or has occurred, in the form of veinlets, varying from a line to possibly an inch or so in width. Although undoubtedly secondary features of the rock, the veinlets clearly antedate the final or complete alteration; and especially do they antedate a large part of the hydration, expan-

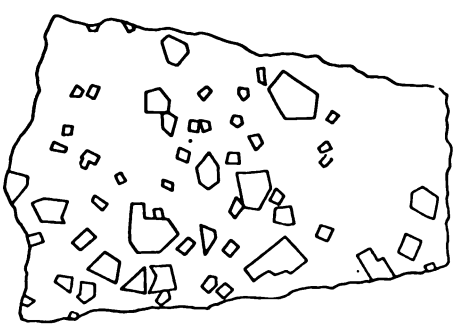

FIG. 3. — Another fragment of the chloritic rock showing, diagrammatically, angular inclusions of quartz, the most of which, at least, are probably due to the comminution of quartz veinlets. One-half natural size.

sion, and consequent slickensiding of the mass, for they have been very extensively broken, dislocated, and even granulated by this differential movement. The chloritization or greenstone alteration of a trap, it is well known, involves the liberation of a large amount of silica, which commonly takes the form of veinlets in the rock, and then during the later stages of the alteration the veinlets may be broken and disarranged. How complete the destruction may be is well shown by Figures 2 and 3, drawn from specimens collected on the dump of the Sterling Mine. The included areas are wholly glassy quartz; but a part of that shown in Figure 3 may not be vein quartz, although the main part of it certainly is, as indicated by the large size and distinctly fragmental forms of the masses. In no instance does the chloritic rock itself, apart from the included quartz, appear to have been crushed or brecciated; but the slickensides suggest, rather, a differential flowing which has brecciated the unyielding quartz veinlets. It is easy to see, in the light of these examples, that with slender veinlets, at least, a complete and seemingly original granulation of the quartz might result. Again, the secondary silica in a case of this kind does not necessarily assume wholly the form of veinlets, but it may have been developed in part as amygdules or pseudo-amygdules, or as irregular segregations and replacements. Certain it is that a trap rock is, during the process of chloritization, a prolific source of free silica, which is unlikely in the case of a large dike to escape wholly, even into cracks in the rock itself, crystallizing in part in interstitial or disseminated forms.

I have not observed the masses described by Professor Smyth as showing gradation from the granite into the chloritic rock or greenstone; but not having read his paper before visiting the locality, I may have overlooked them. I venture the suggestion, however, that they may be inclusions of the granite in the basic dike, which have naturally shared the alteration of the latter and are by simple contact more or less stained or impregnated by the chloritic material. Of course, this might happen to the unbroken granite wall of the dike as well as to inclusions. As showing that granitic inclusions are not wholly wanting, I may add that my collection from the Sterling Mine contains a mass of a distinctly pegmatitic character, in which coarsely crystalline mica is a prominent feature, which I broke out of the soft, dark-green, chloritic rock. It does not, however, show any important alteration, even the mica being still essentially intact. The sandstone

on the opposite side of the dike, although of a distinctly permeable character, does not, so far as I have observed, show any appreciable chloritic impregnation, notwithstanding the fact that it is at some points very deeply stained or impregnated, but not replaced, by the hematite.

As additional evidence that the quartz in the greenstone may be secondary rather than residuary may be mentioned the crystalline quartz occurring with the siderite, chalcodite, millerite, etc., in the

FIG. 4. — An angular quartz geode, due to the replacement of a joint-block of the chloritic rock. About one-third natural size.

pockets of the hematite; and the fact, well attested by specimens in my collection, that the greenstone has been metasomatically replaced by quartz on a considerable scale. One specimen shows the complete replacement of an angular joint-block of the greenstone nearly a foot long and half as thick, forming a sharply angular quartz geode of these dimensions (Figure 4). Even granting that the granular quartz is partly or wholly residuary does not prove the derivation of this ultra-basic rock from the granite, for the original basic rock of this dike may very well have been quartziferous, a quartz-diorite, or possibly a quartz-gabbro. The original rock, while quite certainly not so acid as the granite, was not necessarily highly basic; and the

magmatic segregation of sulphides is by no means confined to rocks exceptionally low in silica; but it is fairly common in rocks of neutral or sub-acid character, and even, as in the case of some of the ore-bearing dioritic rocks of the Sudbury district, in those containing free quartz.

In view of all these considerations, it appears to me most probable that the chloritic rock or greenstone is a highly altered, basic eruptive; although I recognize that some facts point to its derivation from the granite, and especially that the disseminated granular quartz would find thus its readiest explanation. Again, a basic dike six miles or more in length appears far more probable than a sharply defined and apparently persistent zone of granite showing such a radical and unusual transformation as the alternative hypothesis calls for, especially as such a zone of alteration, while unique, and on chemical lines, at least, highly improbable for the granite, is entirely normal for the dike. In other words, if the basic dike be granted, the development of the sulphides in it by magmatic segregation, the chloritization of the silicates while still at a great depth, and the subsequent development of the iron ore by the differential oxidation of the sulphides, appear as entirely normal incidents of its history.

I may add to this that some of my specimens from the Sterling Mine show sulphides, still unoxidized, disseminated in the slickensided chloritic rock precisely as in the diorite of the Sudbury mines and of the Gap Mine; and in this connection it is interesting to note further, that, according to Brooks [1] and several of the sections given by Emmons, the normal position of the iron ore is, more or less distinctly, peripheral with reference to the chloritic rock, thus paralleling another important feature of the deposits having their origin in magmatic segregation.

Since writing this paper, I have had an opportunity to study some of the auriferous veins of the new Michipicoten District of Ontario; and I was specially interested in an occurrence on the southeast side of Lake Wawa, where, during the alteration of a basic dike, the resulting chloritic matter has impregnated and saturated the bordering acid granite to such a degree that the latter rock is completely disguised, the granite falling under the hammer into thin, angular fragments, which are completely coated with the shining, black, chloritic glaze, and being easily mistaken for a chloritized trap.

[1] Am. Jour. Sci., 3d series, Vol. IV., pp. 22–26.

Closer examination shows, however, that the original minerals of the granite are but little altered; and that it is essentially a case of the saturation of a rock along joints and rifts by the secondary mineral of a neighboring rock. This appears to throw some light upon the problem of the quartzose chloritic rock of the Antwerp-Fowler iron mines, and at least suggests the possibility that the quartzose portions of this matrix of the iron ore may be, after all, a phase of the granite. But the basic dike is still required as a source, alike of the impregnating chloritic matter and of the metallic contents of the formation.

GEOLOGICAL HISTORY OF THE CHARLES RIVER.

By FREDERICK G. CLAPP.

Received July 8, 1901.

Introduction.

One of the most interesting streams of Massachusetts is the Charles River, the basin of which occupies a large part of Suffolk County, the western and northwestern portions of Norfolk, a small portion of Worcester, and a strip along the southeastern part of Middlesex County, and includes the whole or considerable portions of twenty-eight cities and towns.

This river is of the utmost importance to the inhabitants of eastern Massachusetts. From its source, in the town of Hopkinton, to its mouth, in Boston Bay, it has a total length, following the meanderings, of sixty-nine miles, and its drainage area is about 290 square miles. Distributed along the river are twenty-six artificial dams, aggregating in height 202 feet, which serve as water power for numerous factories and mills; and one of the dams, in Hopkinton, retains the water supply of the town of Milford. Five other towns — Newton, Brookline, Waltham, Wellesley, and Watertown — obtain their water supply in whole or in part from filter galleries in connection with the river. The tidal portion of the stream is navigable for several miles above its mouth, enabling easy communication with several important manufacturing and other establishments. Picturesque portions, such as Hemlock Gorge, and also stretches lower down on the river, are held by the Commonwealth as public parks. And it is proposed by the Metropolitan Park Commission to improve long stretches of the banks between Dedham and Boston for the public benefit. The tidal portion of the river, between Boston and Watertown, furnishes an exceptional opportunity, by constructing a dam at the proper place, for forming a water park which would be a very valuable addition to Boston's park system. I feel that the present

discussion of the history of the river is especially timely on account of the recent agitation to secure legislation for such a park.

It is impossible to look at the Charles River as represented on the map (Plate 1) without noticing its extremely circuitous course. Rising in the town of Hopkinton, it flows for the first few miles almost directly south. But at Bellingham it bends abruptly to the east, and then to the north, taking a retrograde course as far as West Medway. From this point it runs east as far as Rockville, north and then northeast to Sherborn. Taking a northerly course to South Natick, it there turns to the east, as if to make a short cut to the sea; but at Dedham it bends sharply backward, and flows directly away from the sea as far as Newton Lower Falls, from which point it runs north to Waltham, and then east to its mouth in Boston Bay. Instead of having a length of twenty-five miles, as it would if it ran northeast from its source straight to Boston Bay, the river flows nearly three times that distance. Its transverse meanderings cover a northwest-southeast distance of eleven miles.

In conducting the studies represented in this discussion, the principal purposes kept in mind have been the following:

First.— To give as complete a history of the life of the river as possible.

Second.— To explain why the river follows its present devious course rather than a more direct one. For instance, why does it bend north at Bellingham, instead of continuing southward to Narragansett Bay, the shortest course to the sea? Why, when it has followed a northeasterly course for a dozen miles, does it bend suddenly to the northwest, instead of continuing across Medfield to Boston Bay? Why does it not follow a direct course across Wellesley to Riverside, a distance of three and a half miles, rather than the actual course of seventeen miles by way of Dedham? Again, upon reaching Dedham, why does it not flow straight to Boston Bay, instead of bending back towards Newton?

Third.— To trace the past courses of the river and the causes of the various stages in its development.

Fourth.— To explain the relations of the river and its system to the geological structure of the region, and to determine the causes for such relations.

Fifth.— To determine to which of the recognized classes of rivers the Charles belongs.

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The work undertaken in following out these designs has been mostly done on foot in the field; but besides, I have endeavored to gain access to all recorded information bearing on the subject, and I take pleasure in acknowledging my indebtedness to those who have been of assistance to me in obtaining it: to Professor W. H. Niles, for advice in various ways; to Professor G. H. Barton, for the loan of maps; and to Professor W. O. Crosby, for the use of maps and for much valuable information. For records of bench marks, depths of bed-rock and elevations, I am indebted to the gentlemen connected with the various state and town boards, the Metropolitan Park Commission, the Harbor and Land Commission, the water boards of Boston, Waltham, Newton, Wellesley, and Brookline, and the engineering department of the New York, New Haven & Hartford Railroad. Messrs. B. F. Smith & Brother, Morton & Waugh, and E. A. Clarke have furnished valuable information concerning artesian wells in Boston and vicinity. A list of the various works consulted will be given in the appended Bibliography.

General Description of the Region.

The government topographical map shows that along the western margin of the river basin south of Ashland there extends a high ridge of land having an elevation of from 300 to 600 feet, and forming a natural boundary to the basin. A second, less marked ridge, runs from north to south between Medway and Milford, descending towards the south to the level of the river. With these two exceptions, the highest hills in the Charles River basin rise to elevations of between 300 and 460 feet. As Professor Crosby has shown, the few rock hills of these heights in Eastern Massachusetts are remnants of the Cretaceous peneplain. Between them the Tertiary peneplain is developed, having an elevation of from 100 to 200 feet; and in this less perfect plain the valleys of the Charles and its tributaries have been carved.

The source of the brook which is considered the head of the river is at an elevation of about 500 feet. As is shown by the profile on Plate 2, the descent in the upper part of the stream is very rapid. It crosses the 400-foot contour but one mile, and the 300-foot but two miles, from its source. The 200-foot contour is crossed at Bellingham, twelve miles from the source, and the 100-foot below Natick, about midway in the length of the river. Looking at the profile more

in detail, several points are noticed where the fall is concentrated. At Medway there is a descent of 27 feet in a distance of half a mile. The descent at Newton Upper Falls is 25 feet in a quarter of a mile, and at Newton Lower Falls 22 feet in about the same distance. Between these points of rapid fall there are long stretches where it is very slight indeed. Two of these stretches, one between Rockville and Natick, and the other between Charles River Village and Newton Upper Falls, are especially noticeable.

A great difference exists in the size of the river valley in its different portions. In general, the depression forming the main valley is very broad, but it will be noticed that at several points, as at Medway and at Sherborn, the highlands follow both sides of the river closely for some distance. Especially important are several prominent gaps in the watershed between the Charles and adjacent basins; for example, at Bellingham, Walpole, and Cochituate.

The geological structure of the region is shown in Plate I. It will be seen that the river basin is located in the vicinity of three areas of sedimentary rocks, those of the Boston, Norfolk, and Narragansett basins. These basins are occupied mostly by Carboniferous strata — slates, sandstones, conglomerates, and lavas — which are much softer than the older crystalline formations, the granites, diorites, and felsites, which occupy most of the remainder of the region. For this reason the Carboniferous areas have been worn down, in general, to much lower levels than the harder, crystalline areas (see topographical map).

Outline of the Geology of the Region.

The following discussion will be simplified by giving first a brief outline of the geological history of the whole region since Mesozoic time. During the Cretaceous period the land stood at a level several hundred feet lower than at present, and by long-continued action the sea cut gradually backward, forming the Cretaceous peneplain.[1] As the encroachment continued, sediments formed by marine erosion were spread over the entire submarine surface of the region.

At the close of the Cretaceous period an elevation of the land took place, raising the peneplain with its burden of Cretaceous sediments

[1] W. O. Crosby: Geological History of the Nashua Valley During the Tertiary and Quaternary Periods, Technology Quarterly, Vol. XII, No. 4, p. 289; Geology of the Boston Basin, Pt. 3, p. 538, *Occasional Papers*, Boston Soc. Nat. Hist.

out of the water. From the new land surface thus formed, the streams must have run off, taking the shortest courses to the sea, and utterly regardless of the structure of the underlying harder rocks. At first they flowed upon the unconsolidated Cretaceous sediments; but after these were completely removed by erosion, the solid rocks beneath were attacked, and the formation of a second, the Tertiary peneplain,[1] commenced.

The streams at the time of the Cretaceous elevation were original and consequent upon the slope of the land. As by continued erosion the Cretaceous sediments were entirely removed, the streams became superimposed upon the underlying hard and soft formations. The basin rocks, being least resistant, were removed more rapidly than the outlying crystallines, and the streams gradually shifted their courses on to the softer rocks. Thus they became adjusted, during the Tertiary period, to run in the basins as much as possible. The streams rising on the crystalline areas must have been so adjusted as to take the most direct courses to the basins.

Near the close of the Tertiary period a great elevation of the land occurred, probably amounting to several thousand feet. This increased the energy of the rivers, so that in the bottoms of their valleys they cut deep gorges, extending many miles above their mouths. The gorge at the mouth of the Charles is from 100 to 200 feet deep — below the present sea level. While the land stood at this elevation, the Glacial epoch came on, during which time the whole region was buried beneath the ice sheet, and was covered with a coating of bowlder clay which filled up the Pleistocene gorges and some of the Tertiary valleys. During the recession of the ice to the north, at the close of the Glacial epoch, many of the valleys were blocked by ice or drift, forming large glacial lakes, in which were deposited great quantities of sand and gravel. These overlaid the till in the lowlands and completely changed the character of the topography. Thus when new streams were formed they rarely took their former courses, but instead found new channels across the drift-covered surface in entire indifference to the preglacial conditions.

Preglacial Drainage of the Region.

In order to decipher the courses of the preglacial streams, I will endeavor, first, to show what portions of the present river valley are

[1] *Loc. cit.*

so youthful in their characteristics as to lead to the belief that they have been formed since the Glacial epoch, and then to determine the preglacial courses for these portions. From the fragmentary streams thus discovered, the entire preglacial system of drainage can be constructed with a considerable degree of certainty.

In order to facilitate discussion, it will be convenient to divide the main valley of the Charles into four parts, which can be done very readily on account of the topography. That portion of the river and its valley above Medway I will call the Upper Charles; that between Medway and Sherborn, the Middle Charles; and that below Sherborn, the Lower Charles. The fourth subdivision is the tide-water portion of the river. The sequel will show why these distinctions are made.

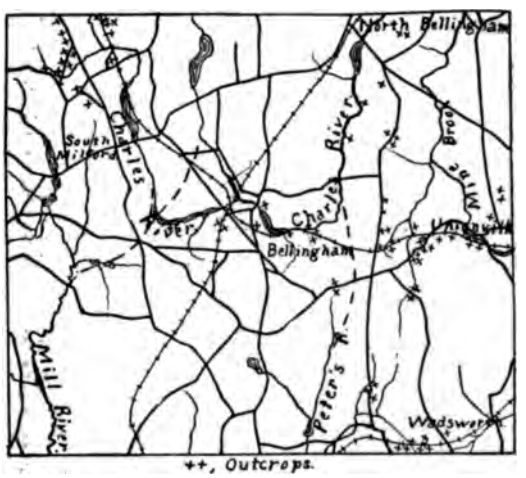

FIG. 1. — MAP OF THE VICINITY OF BELLINGHAM, SHOWING IMPORTANT OUTCROPS.

The Upper Charles. — Rising in the village of Hayden Row, Hopkinton, the river flows for the first ten miles almost directly southward. The valley south of Milford is broad and evidently old. South of Factory Pond it is occupied by an extensive sand-plain. But a mile south of Factory Pond a sudden bend occurs, and the river flows for two miles in an easterly direction. In this stretch the character of the topography is strikingly different from that in the north-south course. Between Milford and Bellingham Junction, with one or two possible exceptions, outcrops of rock nowhere occur within 500 feet of the stream; but below the bend the rock valley gradually narrows down, until, a mile below the Junction, rock approaches close to the river on both banks. The till slopes here come to within a quarter of a mile of the river. The locations of outcrops near the river are shown in Figure 1. On this and subsequent maps I have not attempted to represent all the outcrops, but simply those which concern the present discussion.

By studying Plate 2 it will be seen that while the amount of fall in the four miles above this section is 35 feet, here it is 19 feet in a distance of seven-eighths of a mile. This rate of fall continued for four miles would give 92 feet, showing a much more rapid descent here than directly above. These facts naturally lead to the suggestion that the river is here out of its preglacial course.

Emerging, northeast of Bellingham, from its narrow valley, the

FIG. 2. — CHARLES RIVER AT SANFORD STREET, MEDWAY, SHOWING DAM BUILT AGAINST VERTICAL FACE OF ROCK.

river turns sharply to the north, and flows as far as West Medway through a broad valley, occupied above North Bellingham by meadows 500 to 2,000 feet broad, and having all the characteristics of being very old. Towards the north, however, it narrows, and at West Medway takes a more easterly course.

By referring to the topographical map it will be seen that a broad ridge of high land, overlaid by till, extends south from Holliston to beyond Kelly Street, Medway, within half a mile of the Charles.

South of the river the ridge rises rapidly to a maximum height
320 feet, and extends southward beyond the limits of this stud
Between these two portions of the ridge lies the Medway sand-plai
North of the village, on account of the great thickness of t
plain, not a single outcrop is exposed. To the south, howeve
the river has cut a deep ravine down to the underlying rock,
which it has continued the work of erosion (Figures 2 and 3). With
a distance of half a mile three dams occur.

FIG. 3. — ROCK IN THE MEDWAY GORGE.

The slopes of the Medway sand-plain first approach the river ju
east of Shepard's Brook. Near this point, in order to pass the ridg
of till and its underlying rock, the stream turns to the northeas
Half a mile above Sanford Street ideal erosion slopes rise north
the river to a height of from 60 to 80 feet. All evidences show th
at the close of the Glacial epoch the recently formed sand-plain co
pletely filled the half mile gap in the highlands, and in order to fi
an outlet to the east the stream has had to cut a new valley throug
the plain. It is here, as at Bellingham, out of its preglacial cours

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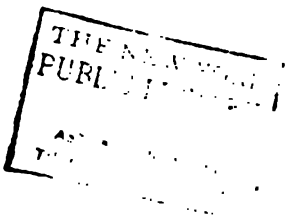

In searching for the former channel we have two alternatives: First — the river may have passed the ledges at Medway through a valley either to the north or south, which is now buried by drift. If to the south, it must have continued eastward from Shepard's Brook to Populatic Pond. The high ridge of till here, however, and the fact that ledges occur all along its northern end, and farther south are exposed on its summit, make it extremely improbable that any buried valley exists here. But if the preglacial valley was north of the present valley, it is occupied now only by modified drift. This course would be possible, but other conditions render it unlikely. It would be extremely improbable, if the Upper Charles flowed east across Medway in preglacial time, that its valley would now be obstructed by such a prominent and uninterrupted north-south ridge as actually exists here. These considerations lead to the natural inference that the underlying rock is continuous from Holliston to Franklin at such an elevation as to bar the way to any preglacial river.

If such is the case, the second alternative must be accepted — that above Medway the direction of the river has been reversed, and that previous to the Glacial epoch it flowed south instead of north; in which case there must be somewhere in the watershed of the Upper Charles a buried valley, the former outlet for the stream. Searching for such a valley, I found its most probable location to be the pass east of Bellingham, where the Charles approaches within a mile of the source of Peters' River, a tributary of the Blackstone. The broad pass at this point is occupied by a sand-plain, and is wholly destitute of outcrops for half a mile east and west (Figure 1). West of Bellingham, at the point where the Charles bends toward the east, there probably exists another buried valley, which in preglacial time furnished an outlet to Mill River. At this point the streams are less than a mile apart, and the watershed between them, in which no outcrops have been found, rises less than 40 feet above the Charles. Careful search has shown this to be the only likely preglacial outlet for the valley northwest of Bellingham. The probable ancient courses are indicated by dotted lines in Plate 3. To summarize, the reasons for believing that the Upper Charles was tributary to Narragansett Bay, as shown in the plate, are: —

1. The valleys both east and west of Bellingham point towards gaps in the watershed on the south.

2. The east-west valley at Bellingham possesses distinctly post-glacial characteristics.

3. The valley from North Bellingham through the gap in the watershed to South Bellingham offers a nearly straight course.

4. The valley south of Caryville is much broader than to the north, and the width increases towards Bellingham. Between Bellingham and Caryville it is too large to belong to a small stream flowing north from Bellingham, but it may easily have been formed by Chicken, Shepard's, Hopping, and Mine brooks combined.

5. The southward course is the shortest route to the sea, being only twenty miles from Bellingham to Narragansett Bay, while to Boston Bay it is twenty-seven miles.

6. The topography and geology in the vicinity of Medway render it improbable that any preglacial outlet existed in that direction. Thus the Bellingham outlet is left as the only alternative.

7. This course would follow the area of metamorphic rocks extending south from Medway. The present course, on the contrary, is from the metamorphic to the harder, igneous rocks.

The Middle Charles. — By referring to the topographical map of the United States Geological Survey, it will be seen that a marked ridge of high land crosses the Charles River basin from the watershed of the Neponset at Cedar Hill to the Charles near South Sherborn, and on the western side of the river crosses to the Sudbury watershed at Paul's Hill in Sherborn. Both north and south of Dover the basin of the Charles varies in width from thirteen to sixteen miles, but this line of highlands narrows it to about six miles (Plate 3). From this well-defined east-west ridge the streams flow off in either direction, giving it the character of a watershed, which, if the river did not run across it, would be a true divide, separating two distinct river basins.

On the eastern side of the river the area of high land is continuous, at elevations varying between 200 and 400 feet above sea level, from Cedar Hill to within a quarter of a mile of the Charles. East of South Sherborn outcrops occur, even down to the level of the river itself. At this point the stream is bounded on the west by a bold granite hill over 260 feet in height, which, just north of the railroad bridge, descends precipitously to the water. The line of steep cliffs extends round the eastern face of the hill for nearly a mile, to the point where the rock on the eastern bank comes close to the river.

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At this place the flood plain is some 400 feet wide, and is divided in the centre by a ledge, say 200 feet across, which rises over 20 feet above the marsh. On the east of this ledge the river flows with a rapid current through a narrow, rocky gorge not over 40 feet wide (Figure 4). The nearly vertical walls of rock rising directly from the water indicate that this was not the preglacial course. Between the above-mentioned ledge on the east and the high hill on the west lies

FIG. 4. — "THE NARROWS," NEAR SOUTH SHERBORN.
The river is flowing through a narrow gorge, the marshes in the foreground being overflowed.

another, wider but similar, gorge, which is occupied by the flood plain of the river.

On the western side of the valley a rock and till ridge runs from the northern end of Pine Hill, west of Farm Pond, southward to Baggistere Brook in Millis. Between this ridge and the granite hill south of South Sherborn station is a gap of half a mile, which might well have been occupied by a preglacial river, except for several indications to the contrary. In the very centre of the gap two prominent ledges of slate occur. Although their presence makes a preglacial

gorge here improbable, it does not make it impossible; so for absolute proof it was necessary to look elsewhere.

For three miles north of the narrow gorge east of the hill the valley is one of varying character, in which numerous ledges occur, sometimes close to the river. A mile northeast of Farm Pond, near Clark Rock, conglomerate ledges descend on both banks into the water. West of Pegan Hill felsite rises abruptly both on the east and west, forming a narrow U-shaped gorge. East of the bend at this point the line of high land is continuous. To the west, ledges of felsite extend almost continuously across South Street to Long Pond, and from there northward to within 400 feet of Eliot Street (Figure 5). Nowhere do they offer a gap wide enough for a preglacial river valley. The only break which could be seriously considered is 600 feet wide, lying between the most northern felsite outcrop and the melaphyre, which outcrops 200 feet north of Eliot Street. About midway between these ledges, however, is a well, said to be about 20 feet deep and to rest on solid rock. Between here and Natick ledges are almost continuous. Considering these proofs, and also that in preglacial time the bed of the river must have been over a hundred feet below its present level, I believe we have conclusive evidence that between Dover and Natick there was no gap of sufficient size to connect the Middle with the Lower Charles. This evidence is strengthened by the presence of numerous ledges in the vicinity of South Natick.

FIG. 5. — OUTCROP MAP OF A PORTION OF THE REGION BETWEEN MEDFIELD AND NATICK.

Nevertheless, the broad expanses of valley in the basin of the Middle Charles show that the region must necessarily have been traversed by streams of considerable size. As the outlets of these ancient streams cannot have been to the north, they must be searched for in some other direction. To find them, an analysis must be made of the valley of the Middle Charles.

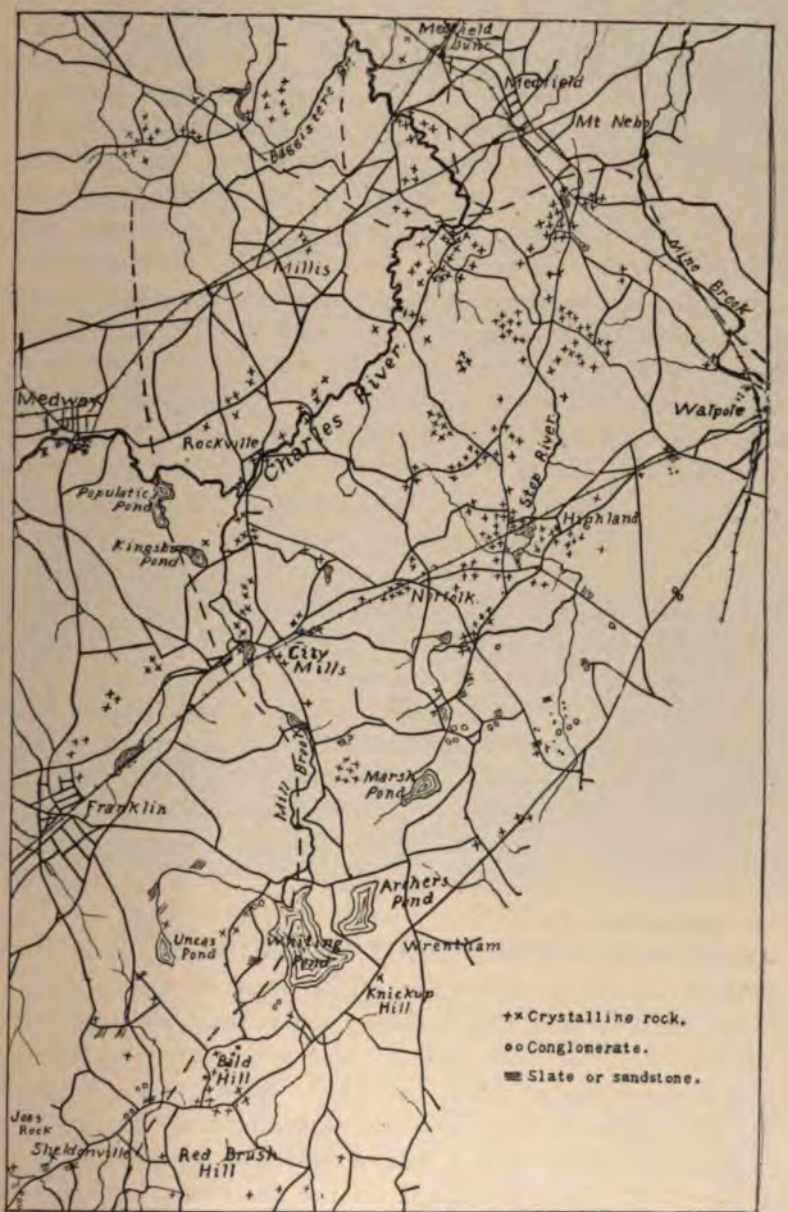

FIG. 6. — OUTCROP MAP OF A PORTION OF THE BASIN OF THE MIDDLE CHARLES AND VICINITY.

Flowing out of the narrow Medway gorge, the contrast is very great, as the river emerges into a broad, open valley, entirely devoid of outcrops, and with every characteristic of being very old. It flows in this valley for a mile and a half, as far as Green Street. Here, however, the characteristics suddenly change, and the direction becomes northeasterly for four miles, throughout which distance outcrops are occasional (Figure 6) and the topography rather characteristic of a distinctly postglacial stream. North of Forest Street an old valley is again encountered. In it the river turns eastward, as if to round the north side of Noon Hill; but instead, at the mouth of Stop River it turns towards the northwest. Stop River is a large tributary entering the Charles from the east, and at its mouth appears almost equal in size to the main stream. Its valley is certainly much broader, as shown by the contours. Between the 120-foot contours it is occupied by extensive meadows. Below its mouth, the valley of Stop River is continued with a width of from half a mile to a mile as far as Canal Street in Medfield, but interrupted near the Woonsocket Division of the New York, New Haven & Hartford Railroad by a series of outcrops (Figure 6). West of the railroad the broad valley is especially marked, as shown in Figure 7.

The topography shows that in the basin of the Middle Charles two portions are so broad and low that they must have been occupied by preglacial streams of considerable size. The first of these, lying between Medway and Rockville, I will call the Populatic River, from Populatic Pond. The other river, between Medfield and Millis, I will call the Baggistere, as it had its source in Baggistere Brook. The next problem is to determine the outlets of these preglacial streams from the basin.

By referring to Plate 1 it will be seen that the most prominent geological feature in this region is the band of Carboniferous sedimentary rocks forming the Norfolk County Basin, and stretching with a variable width of from one to three miles from the Narragansett Basin, at the northeast corner of Rhode Island, to the Boston Basin, north of the Blue Hills. This band of sedimentary rocks coincides to a considerable degree with a belt of lowlands, occupied on the northeast by the Neponset River and on the southwest by Abbots's Run.

At the beginning of the Glacial epoch sufficient time had elapsed since the origin of the streams of the region to enable them to become adjusted to the geological structure. Thus the streams originating

upon the crystalline areas to the northwest and southeast of the Norfolk Basin had come to take the most direct courses to the softer, sedimentary rocks. Of these streams the Populatic and the Baggistere were the most important.

The source of the Populatic River was in the western part of the town of Sherborn, at one of the sources of Baggistere Brook, with which it coincided as far as Orchard Street. It followed the broad, swampy valley south of Orchard Street as far as the present Charles.

FIG. 7. — VALLEY OF CHARLES RIVER WEST OF THE WOONSOCKET DIVISION OF THE N. Y., N. H. & H. R. R., BETWEEN MEDFIELD AND MILLIS. MARSHES OVERFLOWED.

Farther south its course is marked by Populatic and Kingsbury ponds and Mill Brook, which it followed to the Norfolk Basin. Throughout almost the entire distance the bed-rock outcrops frequently along the western border of the valley, but it is exposed in the valley itself only near City Mills. Nowhere does it forbid regarding this as a preglacial course. Upon reaching the basin rocks the Populatic must have taken one of two courses. It may have turned northward to join the Neponset, or southward towards Abbots' Run. The latter course is the more probable. Nowhere between Marsh Pond and Walpole can evidences of a buried valley be found. But a southward sloping valley

between Whiting Pond and the gap west of Bald Hill in Wrentham would follow the narrow band of sedimentary rocks connecting the Norfolk and Narragansett basins. In the absence of any other plausible outlet for the Populatic River, we must accept this as its most probable location.

The Baggistere River was probably formed by the union of several brooks in the broad valley northwest of the Woonsocket Division, near the mouth of the present Baggistere Brook. The exact point of junction of the brooks must have been near the railroad in the vicinity of Island Street. Continuing the direction of the resultant of their courses towards the southeast, a broad, drift-filled valley is reached, extending to the marshy area south of Dwight Street. Near Causeway Street the river was joined by the brook flowing south from Castle Hill. East of here its most probable route is across the low watershed into the valley of Mine Brook, and thence to the Norfolk Basin. The probability of this is indicated by the broad, low valley of Mine Brook along the railroad between Medfield and Walpole. At first the great amount of rock east of Mt. Nebo seemed an obstacle to any preglacial course here. More careful examination, however, shows that most, if not all, of the rock between the railroad and Mt. Nebo is moraine material, and that the north-south ridge north of the railroad is a moraine separating the two valleys. An alternative course for the ancient river east of Causeway Street is through the valley of Stop River east of Noon Hill. This valley is less direct, however. Whichever course the river took, it joined the Neponset in the vicinity of Walpole, and was tributary to Boston Bay.

To summarize briefly, the basin of the Middle Charles was, in preglacial time, drained by two main streams, the Populatic and the Baggistere, both rising in Sherborn and flowing very directly to the Norfolk Basin. The Populatic reached the basin rocks north of Wrentham, then found an outlet to the Narragansett Basin, and thence to the sea through Miller's River and the Blackstone. Baggistere River, on the other hand, entered the Neponset Valley, which it followed to the sea through the Norfolk and Boston basins.

The Lower Charles. — We have seen that at the beginning of the Glacial epoch no part of the drainage south of Dover and Sherborn was tributary to the region on the north. Still, the broad valleys at several points below South Natick indicate that they must have been occupied by streams of considerable size.

South of the village of South Natick many prominent outcrops border the river and many occur even in its bed. Most of the higher lands both west and south of South Natick consist of solid rock. And this notwithstanding the fact that a long arm of the sedimentary and volcanic rocks of the Boston Basin extends as far west as Farm Pond (Plate I and Figure 5). At South Natick the outcrops extend across nearly the entire breadth of this belt, indicating that in preglacial time there was no large stream flowing into the Boston Basin through this area.

Below South Natick, following the river, we pass from a region of frequent outcrops to one where they are very scattering, and once more reach a portion of the valley which is undoubtedly very old. Between the ledge of melaphyre just below the dam at South Natick and the ledges near the corner of Dover and Grove streets, Wellesley, no outcrops occur, with the possible exception of a conglomerate exposure, perhaps a bowlder, on the Hunnewell estate. The outcrops in Wellesley and Needham are shown in Figure 8. The broad valley east of South Natick expands in two directions, extending far up the valley of Trout Brook, and also across Lake Waban and Morse's Pond, towards Cochituate. It probably also extends northward beneath the drift deposits of Wellesley and Needham. The sand-plains of this region rise to an extreme elevation of about 160 feet, in places rising steeply from the river in postglacial erosion slopes. Usually, however, the slopes are gradual, due to construction, and having been little eroded by the river. Near the mouth of Trout Brook the valley is very broad, but narrows down towards Charles River Village. Between Central Avenue and South Street outcrops are thick all along the river. The tortuous course between the ledges shows it at once to be of postglacial origin.

At South Street is a dam 8 feet in height, and below this outcrops occur on both banks, as shown in Figure 8. Just west of Chestnut Street ledges approach very near the river on both north and south, showing a strong probability that this was not a preglacial course. This is conclusively proved east of Chestnut Street, where a line of ledges crossing the river extends, both on the north and south, far back from the stream, offering no gap wide enough to contain a buried valley. The impossibility becomes still more evident when we consider that the bed of the preglacial stream must have been at least 100 feet below the present channel, as will be shown later. Between

FIG. 8. — OUTCROP MAP OF A PORTION OF THE BASIN OF THE LOWER CHARLES.

Chestnut Street and Greendale Avenue the abundant outcrops near the river strengthen the proof that this part of the course is of post-glacial origin.

In the vicinity of Greendale Avenue the entire character of the valley changes, and the Charles emerges into a broad meadow, extending to the north for over two miles. Instead of following this direct course, the inconsistent river turns suddenly to the south towards the narrower end of the valley, and, reaching its termination west of Dedham Village, is forced to find a passage between the granite ledges which border it as far as Ames Street. At this point a broad, marshy

FIG. 9. — CHARLES RIVER MEADOWS ABOVE NAHANTON STREET, BETWEEN NEWTON AND NEEDHAM. (HIGH WATER.)

valley is again encountered, and turning at an acute angle, the river flows off to the northward. Half a mile below Ames Street an artificial ditch has been cut through the low divide on the east, diverting part of the water of the Charles into the rocky valley of Mother Brook leading to the Neponset, and thus making Boston an island. North of this the Charles flows sluggishly through broad marshes, which unite, west of Cow Island, with the marsh already noted, east of Greendale Avenue. This portion of the valley is clearly very old (Figure 9). But at Nahanton Street a ledge of melaphyre rises east of the river, and northeast of here the valley rapidly narrows. At Highland Avenue conglomerate occurs close to both banks; and south of High-

land Avenue and a quarter of a mile from the river a bold hill of felsite rises to an elevation of about 170 feet.

Below Central Avenue there is a sheer fall of 13 feet, and the river enters the picturesque Hemlock Gorge, and flows through it between steep ledges of conglomerate, which rise precipitously from the water. Figure 10 shows the distinctly postglacial character of the gorge. Below Worcester Street is a second dam, with a fall of 15 feet,

FIG. 10. — VIEW IN HEMLOCK GORGE, SHOWING THE UPPER FALL.

making the total height of Newton Upper Falls about 28 feet. Passing out of the gorge below Worcester Street, the stream again reaches a broad, low valley, through which it flows westward until, just below the mouth of Rosemary Brook, it strikes a ledge of conglomerate and turns slightly to the north. Beyond this point high sand-plains close in ; and at Newton Lower Falls the valley has become very narrow, having without doubt been eroded by the river, as is indeed indicated by excavations in the steep slopes of the sand-plain. Enough sand has been removed so that the horizontal strata are seen to be cut off abruptly by the erosion slopes. In the bottom of the valley

at this point ledges of melaphyre occur, extending entirely across the river, and, together with artificial damming, making falls the total height of which is about 22 feet (Figure 11). Below Newton Lower Falls the river passes on to a band of soft rocks, and once more finds itself in a broad valley devoid of outcrops. A mile west of the falls it strikes the crystalline border of the Boston Basin, and is turned to the northeast towards Riverside. Between Riverside and Waltham

FIG. 11. — UPPER PORTION OF NEWTON LOWER FALLS.

outcrops are abundant on the west bank, occurring at Prospect Street, close to the water. On the east side of the river, the only ledges north of the Boston & Albany Railroad are several exposures of slate west of Auburndale. Below Waltham no outcrops occur near the river, except a ledge 100 feet south of the Bemis dam, and below this the nearest are 1,000 feet from the river, in Newton, opposite Watertown. Between Riverside and Cambridge there is no indication that the river is at any point far from its preglacial course.

This brief survey of the topography of the valley of the Lower Charles seems to warrant the following conclusions: —

1. That above South Natick there could have been no preglacial stream larger than a mere brook.

2. That in the regions between South Natick and Charles River Village, between Dedham and Newton Upper Falls, and between Newton Lower Falls and Riverside the valley is typically old.

3. That at both the Upper and Lower Falls, and between Charles River Village and Dedham, the Charles is certainly out of its preglacial course.

The explanation of these phenomena is found in evidence showing that the large basin between Dedham and Newton was formerly occupied by a separate stream, while the main river cut across Needham to its present valley below the Lower Falls.

It is probable, however, that the preglacial Charles did not have its principal source, as might be supposed, in the valleys of Natick and Dover; but that it rose far to the northwest. A peculiarity of the Sudbury River is the fact that, although in the upper part of its course it flows directly towards the Boston Basin to within five miles of its border, instead of taking the direct course of twenty miles to the sea across the softer basin rocks, it turns northward in the vicinity of Framingham to unite with the Assabet at Concord, forming the Concord River, which is tributary to the Merrimac at Lowell, and thence to the sea at Newburyport, making a total distance from Framingham of seventy-five miles. This course is evidently very unstable, and it must have been impossible for it to survive the complex stream adjustment which took place during the Tertiary period. The natural explanation is that between Concord and Saxonville the drainage has been reversed, and that in preglacial time the river had its source near Concord, flowing southward to the Charles through a valley now indicated in part by the basins of Morse's Pond and Lake Waban.

Outcrops occur on the east slope of Train Hill, opposite Wellesley College, and at Blossom Street, Wellesley; but between these points none have been found. Moreover, between the Sudbury west of Reeves' Hill and the Charles there is room for a buried valley over a mile wide, as shown by the absence of outcrops (Figure 8). A line drawn through Dudley, Pickerel, Jennings', and Morse's Ponds and Lake Waban, all kettle ponds, would mark approximately the most probable location of the buried valley. A convincing proof that such a valley lies beneath Wellesley is afforded by the record of a well

bored on the Mayo Farm, on Blossom Street, a mile north of the railroad. The well is located not far from the 160-foot contour, and went through 90 feet of sand and gravel without striking ledge. It must extend about 40 feet below the surface of Morse's Pond, and as it is apparently not in the direct line of the preglacial valley, it is extremely probable that the lowest line or axis of the gorge is at a much lower level. As further evidence that this was the course of the preglacial Sudbury River, it may be added that: —

1. The Sudbury River meadows are very narrow in the vicinity of Concord, but widen towards the south.

2. At several points near Concord outcrops occur near the Sudbury and Concord Rivers.

3. The tributaries of the Sudbury — Stows, Baiting, Wash, Hayward, and Cold Brooks — tend to converge toward the south rather than the north.

4. The portion of the Sudbury above and that below Cochituate converge toward this preglacial outlet.

The west branch of the Sudbury, flowing east from Westboro, must have combined with the north branch in the vicinity of Cochituate to form the Charles. It is probable that at that time the Assabet was tributary to the Sudbury through either Pantry or Hop Brooks. Thus the entire area now included in the Sudbury and Assabet basins drained into the Charles, which must, consequently, have been a stream of considerable size.

Upon reaching the Boston Basin the Charles probably turned northeastward and followed the basin rocks out to sea. An extended study has shown that between Wellesley and the Charles River east of Chestnut Street, Needham, outcrops are so thick that there are only two possible routes for the preglacial valley. One of these is eastward beneath Ridge Hill, and then northward between the felsite and melaphyre outcrops south of North Hill. The other, more direct and more probable, course is directly east from Lake Waban between the granite and sandstone outcrops, and beneath two large drumlins, to the valley of Rosemary Brook. The probability of the valley of this brook having once been occupied by the Charles is evident from its great size (Figure 12). It is out of all proportion to the size of the diminutive stream which now meanders through it; and north of Needham it is, for a width of a mile and a half, entirely free from outcrops almost to Newton Lower Falls.

The great size of this part of the ancient valley may have been due in part, however, to a stream flowing into it from the basin on the east. The principal tributaries to this basin were South Meadow, Palmer, and Wigwam Brooks, which united to form the broad valley along the western end of the West Roxbury slate belt. Evidence, aside from the surface topography, that a deep buried valley exists here is afforded by the records of numerous wells. At the Pumping Station of the Brookline Water Works, on the southwest point of Cow Island, a number of wells have been sunk to a depth of 90 feet below the surface. One of them strikes ledge at that depth. As the elevation of the surface at this point is about 93 feet, the wells evidently reach nearly to sea level. Beginning a mile northeast of this, and extending as far as Highland Avenue, numerous wells have been sunk for the Newton Water Works, the results of a few of which are given below.

WELLS ALONG THE PIPE LINE 25 TO 300 FEET SOUTH OF THE RIVER, BETWEEN STATION 0, 2,050 FEET NORTHWEST OF KENDRICK STREET, AND STATION 20 + 50, AT KENDRICK STREET.

STATION ON PIPE LINE.	ELEVATION OF BOTTOM OF WELL REFERRED TO SEA LEVEL. (In feet.)
Station 2 + 60	+ 43
Station 5 + 10	+ 20
Station 7 + 60	+ 13
Station 8 + 80	— 7
Station 9 + 30	— 34
Station 9 + 60	— 27
Station 9 + 80	— 35*
Station 10 + 20 to 10 + 50	— 20
Station 11 + 10 to 12 + 60	0 to + 10*
Station 12 + 10	— 35*
Station 16 + to 20 + 50	+ 50 to + 70
Station 20 + 50, 265 feet from river	+ 55

* Bed-rock not reached.

All the above wells reached bed rock at the depths given, except those at stations 9 + 80, 11 + 10 to 12 + 60, and 12 + 10, in which cases no rock was encountered. South of Kendrick Street and west

of the river the wells are all very shallow, no rock being reached in any case. Along the eastern side of the river another line of wells has been driven. The most westerly of these, some 2,000 feet south of Nahanton Street and 50 feet from the river, reaches bed-rock at an elevation of +16 feet. East of here the rock surface rises to + 36, 43, 47, and 57 feet in successive wells. The results of these borings show, first, that throughout this basin there is a deep buried valley extending east and west; and second, that about 1,000 feet north of Kendrick Street a buried gorge of great depth trenches the bottom

FIG. 42. — VALLEY OF ROSEMARY BROOK AT WEST STREET, WEST OF HIGHLANDVILLE.

of a north-south valley. This gorge, bounded as it is by outcrops on the east and west, must belong to a preglacial stream which was tributary to the east-west stream occupying the main valley, as described above. As the depth of the main valley must be at least as great as that of its tributaries, we must conclude that this, also, had a depth of *at least* 35 feet below sea level. And if this stream flowed westward into the Charles, the floor of that valley must have been still lower.

It has generally been supposed heretofore that the preglacial channel of the Charles around Newton Upper Falls diverged from the present river above Kendrick Street, passing south of the felsite

hill and through a narrow pass beneath the Sudbury Aqueduct just east of Cedar Street to the broad meadows in the vicinity of Worcester Street. A more direct and more probable course, however, is directly westward from Kendrick Street to the valley of Rosemary Brook west of Highlandville. Along this line there is a gap over a mile in width occupied by the sand-plain, having an elevation of from 120 to 140 feet, above which not an outcrop appears (Figure 8). In the gap at the aqueduct, on the other hand, the breadth of the bed-rock valley on the surface is certainly less than 600 feet, and probably less than half that. The lowest elevation of the surface is about 105 feet; but on both sides of this point, a few hundred feet distant, ledges rise to elevations up to 160 feet. Thus, although nothing has been found to absolutely disprove this route, we must accept the Highlandville course as the more probable of the two.

The only objections to a westward flowing stream here are that the course is retrograde, and that it passes from the slate belt to the harder felsite to the west; but this may be partly explained by assuming that formerly the slate was continuous westward to the valley of the Charles. A possible alternative course for the Charles would be to consider that, instead of turning north towards Waltham, it flowed eastward from Highlandville and followed the slate belt out to Boston Bay, across West Roxbury and Dorchester. I have considered this view, but have been able to find no direct evidence to sustain it. Moreover, at several points along the slate belt the gaps between the outcrops are so narrow as to render the course improbable. This is especially the case east of Franklin Field, Dorchester, where slate has been thrown out in excavating for sewers. For similar reasons, any attempt to trace a preglacial outlet through the valley of Stony Brook must be abandoned. An outlet along Mother Brook is impossible. Although this stream crosses the Neponset-Charles watershed at its lowest point, the channel is so tortuous and rocky that it cannot be considered for a moment.

We must, then, suppose that from near Highlandville the course of the preglacial Charles was northwest to the present river below Newton Lower Falls, and that from there on it had approximately its present location. The existence of a deep gorge below the present river at Waltham is shown by several wells in that vicinity. A well at the Waltham Bleachery was driven to a depth of 70 feet below and one at the American Watch Tool Company to 63 feet below sea level

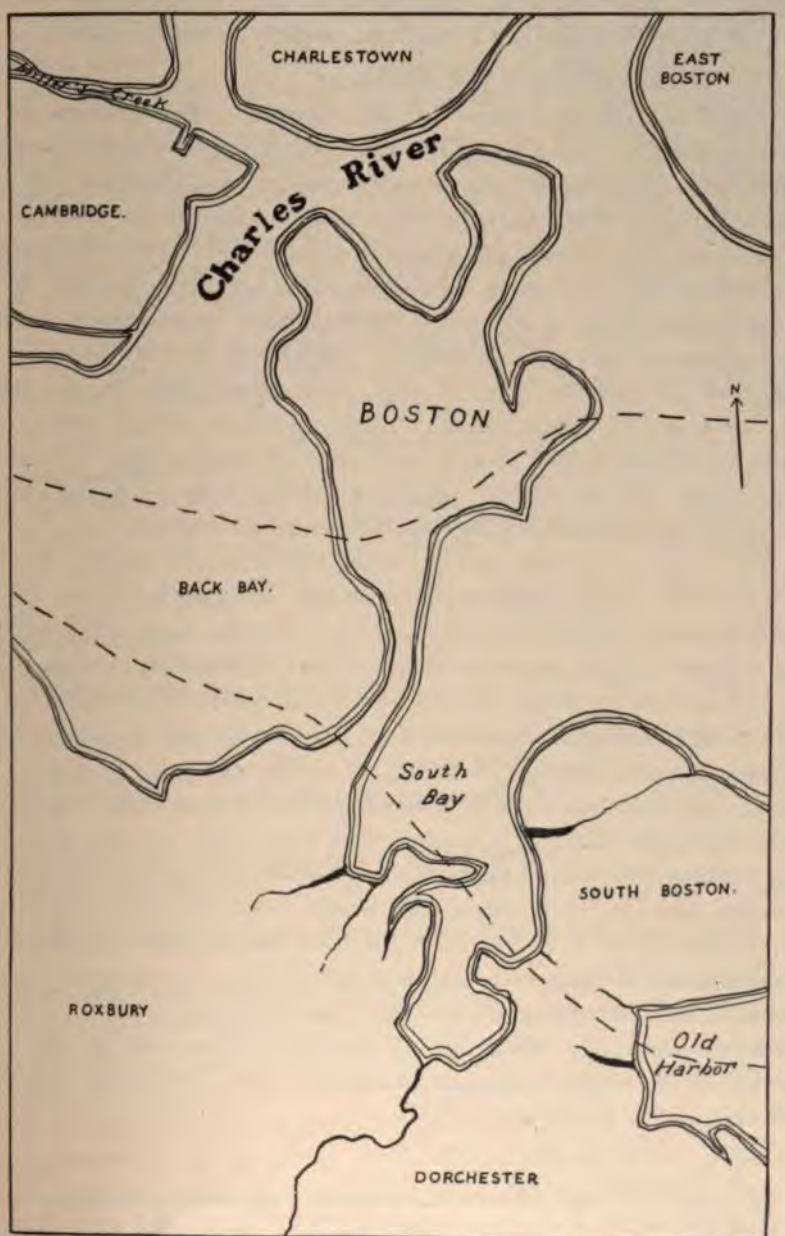

FIG. 13. — OUTLINE MAP OF BOSTON AS IT WAS BEFORE THE POSITION OF THE SHORE LINE WAS CHANGED BY ARTIFICIAL FILLING. (From an old map.)

without reaching bed-rock. And wells at the Waltham Gas Company and the Davis & Farnham Foundry Company reached ledge at depths of —40 and —62 feet, respectively.

The Tide Water Portion of the Charles. — The portion of the Charles southeast of Cambridge unquestionably overlies a preglacial valley. In planning for the construction of the Harvard and West Boston bridges many borings were made to depths varying between 30 and 80 feet, none of which reached bed-rock. Around the northwest side of Beacon Hill, however, according to Mr. W. W. Dodge,[1] rock rises to sea level and has been encountered in many excavations for sewers and cellars. In boring for the bridge of the Boston & Lowell Railroad, in 1833, rock was struck on the Boston side 12 feet below low water. These and many other similar facts make it probable that a continuous ridge of rock passes beneath the river north and northwest of Beacon Hill, presenting an effective barrier to an ancient channel on this side of Boston.

The true preglacial valley must, therefore, lie to the south of Beacon Hill. Until the latter part of the nineteenth century the city was connected with Roxbury only by a narrow neck of land along Washington Street, between Pleasant and Dartmouth streets (Figure 13). The land on either side of this neck, out to the present bank of the Charles on the west and to Fort Point Channel on the east, has all been formed by artificial filling. Dorchester Neck, between South Boston and Dorchester, is at present but half a mile across, and in the early days consisted of a marsh, which at times of very high tides was entirely covered, making South Boston an island. In the area between Beacon Hill and a line drawn from Roxbury Crossing to Mt. Vernon Street, Dorchester, there is not a single outcrop, with the exception of ledges in South Boston. The topography suggests at once that the early pleistocene course of the river was east or southeast from the Back Bay. And such a course is practically proved by numerous artesian wells, the data for a few of which follows.

[1] Notes on the Geology of Eastern Massachusetts. Proc. Bos. Soc. Nat. Hist., Vol XXI, pp. 197–215.

IN BOSTON PROPER.

	Location.	Depth of bed-rock in feet.
1.	Post-Office Square	105 [1]
2.	Edison Electric Illuminating Co., Liverpool Wharf, Atlantic Avenue, opposite Pearl Street	83
3.	Federal Court — Federal Street	80
4.	Atlantic Avenue, corner Congress Street	90
5.	Boring for Congress Street Bridge	43.5
6.	Adams House, 553 Washington Street	120
7.	Near Old Elm, Boston Common	105 [1]
8.	Old Boston & Providence Railroad Station, Park Square	163
9.	Hotel Plaza, corner Columbus Avenue and Holbrook Street	99
10.	53 West Brookline Street, corner Washington	83
11.	Allen Gymnasium, corner St. Botolph and Garrison Streets	140 [1]
12.	791 Tremont Street, corner Northampton	170
13.	Corner Swett and Albany Streets	105 [1]

IN CAMBRIDGE.

14.	Near outlet of Fresh Pond	148
15.	Brigham's, Massachusetts Avenue, Cambridgeport	120
16.	Soap Works, corner Davis Street and Broadway, Cambridgeport	110–115
17.	John P. Squires & Co., Gore Street, East Cambridge	60

IN SOUTH BOSTON AND DORCHESTER.

18.	Pier 4, South Boston	118 [1]
19.	Just to south, on next pier	35
20.	Old Calf Pasture, Mt. Vernon Street	166

ON LINE OF SEWERAGE TUNNEL FROM CALF PASTURE TO SQUANTUM.

21.	West Shaft, Pumping Station	over 100
22.	Rock rises towards the east to about level of low water.	
23.	North of Dorchester Street exists a ledge of slate, which was formerly quarried.	
24.	Dredgings in the harbor have struck rock in many places between Castle and Governor's Islands.	
25.	North of Governor's Island borings of 40 feet have failed to reach rock.	

Comparing these data, it is seen from 14, 15, and 16 that beneath Cambridgeport the bed-rock is from 110 to 150 feet below sea level, but that it rises towards the north, as shown by 27, forming an east-west ridge extending as far east as Beacon Hill. In Post-Office Square the rock surface is again very low (1). South of Beacon Hill is an east-west gorge of great depth (6, 7, and 8), which probably passes eastward between Post-Office and Dewey Squares; and 25 indicates that the gorge may be extended eastward between Governor's Island and East Boston. South of Park Square the bed-rock

[1] Bed-rock not reached.

rises, as shown by 9 and 10, to between 80 and 100 feet below sea level, forming a ridge which is shown by numerous outcrops in South Boston and Boston Harbor to be continued as far east as Castle Island (23 and 24). South of this ridge is a second deep gorge. The lowest rock surface shown by the records is at 791 Tremont Street, near Northampton (12), where it is nearly 170 feet below sea level.[1] Borings 13, 20, and 21 show this gorge to be extended east between South Boston and Dorchester to the Old Harbor.

Thus the preglacial gorge of the Charles beneath Boston must have one of two locations. The course most in line with the river to the west would be the more northern one. But the bend which would be necessary in that case between the outcrops west of Beacon Hill and the comparatively shallow borings near Dewey Square is an unnatural one. A straighter course, and one giving room for a wider gorge, is the southern one, which is also the one in which the lowest bed-rock surface has been found (12, 20).

Moreover, the deep borings in Cambridge are exactly in line with the southern gorge, and the topographical map shows that, with a slight bend to the north, the surface depression here continues with an average width of two miles across Belmont and Arlington to the Mystic Lakes at West Medford. Professor Crosby has shown[2] that the Merrimac River in preglacial time was probably tributary to Boston Bay. If such was the case, its most direct course would be southward from Arlington along this depression to the Old Harbor. Hence the preglacial Charles was a branch of the Merrimac, meeting it in the vicinity of Cambridgeport. An alternative course for the Merrimac is eastward from West Medford through the valley of the Mystic; but as this would necessitate a sharp bend at West Medford, I consider it less probable.

As the Pleistocene elevation of the land carried the shore line in the vicinity of Boston much farther east than it is at present, the streams of that time had to cut their gorges in rock which is now deeply buried beneath the bay. Two courses must be considered for the Charles (or the Merrimac) after reaching the Old Harbor: a northern one, passing just south of Castle Island, and thence north-

[1] As the elevation of the land between Beacon Hill and Roxbury is but a few feet above high water, it may practically be neglected here.

[2] Geological History of the Nashua Valley, *l. c.*, p. 302.

east; and a southern one, towards Thompson's and Moon Islands and Nantasket. Between Nash's Rocks, north of Point Allerton, and Moffit's Ledge, over two miles farther north, ledges are so frequent as to afford no probable location for a valley. This band of ledges, trending approximately northeast and forming the Outer Islands, is a continuation of the line of outcrops in the lower Neponset Valley, and exposed in Squantum, on Moon Island, and in Sculpin Ledge. It is improbable that this ridge was crossed by the preglacial channels of either the Neponset or the Charles, but it more likely formed a divide between them. Moreover, northeast of the Calf Pasture extends a broad, open area, unobstructed by any land, except Deer Island, which is a drumlin; and this is regarded as the most probable course of the submarine gorge of the preglacial Charles.

[To be concluded in the next number of the QUARTERLY.]

RESULTS OF TESTS MADE IN THE ENGINEERING LABORATORIES.

XIII.

STEAM, HYDRAULICS, AND APPLIED MECHANICS.

MEASUREMENT OF AIR WITH AN ORIFICE.

THE increasing use of compressed air as a motive power makes desirable some simple method of determining the quantity of air consumed. At present we have only Fliegner's formulæ, based upon his experiments with two small orifices, 4.085 mm. and 7.314 mm. in diameter and with pressures under five atmospheres.

To test the availability of these formulæ for larger orifices and higher pressures, and if necessary to establish new formulæ, the apparatus shown in the accompanying cut (Figure 1) has recently been installed in the Mechanical Engineering Laboratory.

The battery of twelve tubes, tested to stand hydraulic pressure of 3,500 pounds per square inch, is piped to form three units of two and two units of three tubes each, thus permitting the use of any number at once. Because of the difficulty in preventing leakage through the connecting valves, it has been found advisable in practice to use the entire reservoir. The slight leakage about the stuffing boxes can be so minimized as to be negligible. These supply tubes are connected by piping to a large receiver, the admission of the air being controlled by a throttle valve placed in this pipe. The receiver has a safety valve set at about 350 pounds, so this determines the maximum pressure that can be used with the present arrangement.

The orifices are all made with the length of the cylindrical part one and one-half times the diameter and with a radius of the rounded approach equal to the diameter. The orifices were carefully made by a

FIG. 1. — APPARATUS FOR THE MEASUREMENT OF AIR WITH AN ORIFICE.

skilled workman, care being taken to avoid any scratches which might affect the passage of air. When finished the diameter of each was carefully determined by fitting an arbor of slight taper into the hole and calipering the arbor with a micrometer caliper. At the centre of the straight cylindrical part of the orifice is a hole $\frac{1}{64}$-inch in diameter, drilled at right angles to the axis of the orifice and connected by piping to a pressure gauge.

The reservoir and receiver were fitted with gauges and thermometers. These instruments were carefully calibrated and the corrections applied to all the readings. The volume of the receiver and each of the twelve tubes was obtained by weighing the amount of water of known density necessary to fill them, and that of the piping was calculated from careful measurements. The total volume of the twelve tubes and the piping down to the throttle valve is 49.11 cubic feet (V_1), and of the receiver and piping from the throttle valve is 41.14 cubic feet (V_2).

To make an experiment the orifice was first closed with a wooden plug held against it by means of a lever, and then the pressure and temperature of the air in both the receiver and the tubes forming the reservoir were recorded. Air was next admitted to the receiver until the desired pressure had been obtained, when the orifice was uncovered and a stop watch was started simultaneously. Readings were then taken, at half-minute intervals, of the pressure in the orifice and of the pressure and temperature in the receiver. At the close of the test, produced by closing the throttle valve, the watch was stopped, and at the same time final readings were taken of the pressure and temperature in the receiver. During the test the pressure was kept nearly constant by regulating the throttle valve, but the temperature in the receiver would rise rapidly at first and then gradually fall again as colder air came in from the reservoir. At the close, after the temperature in the supply tubes had become constant, a final reading was taken of the pressure and temperature. As it takes some two or three hours to fill the tubes to a pressure of 2,500 pounds to the square inch, and only about 3 minutes to empty them with a $\frac{5}{8}$-inch orifice, it was found advantageous to save as much of the air as possible; so at the end of some of the tests the plug was replaced before all the air had escaped from the receiver. This accounts for the initial pressure (P_0) so often being different from atmospheric pressure.

The air was supplied by a three-stage Norwalk Air Compressor, and contained from day to day varying amounts of moisture and also of cylinder oil. It was assumed, in working up the results, that the air followed the law of perfect gases up to 200 pounds pressure on the square inch, and that above 200 pounds it follows the same deviation as the dry air experimented upon by E. H. Amagat. Interpolating the pressures in Amagat's results gave the specific volumes (V_1, V_2) at 32° F. From these and the observed temperatures were obtained the densities of the air in the reservoir before and after the test (w_1 and w_2, respectively), and also in the receiver before starting and at the moment the throttle valve was closed (w_0 and w_3, respectively).

The weight of air that has passed the orifice is equal to that which has left the tubes minus the increase of weight in the receiver, or the weight per second is

$$G = \frac{1}{S}\left[V_t (w_1 - w_2) - V_R (w_3 - w_0)\right]$$

where

G = pounds of air passing orifice per second.
S = duration of test in seconds.
V_t = volume of reservoir = 49.11 cubic feet.
V_R = volume of receiver = 41.14 cubic feet.
w_1 = weight of 1 cubic foot of air in tubes at start.
w_2 = weight of 1 cubic foot of air in tubes at close.
w_3 = weight of 1 cubic foot of air in receiver at close.
w_0 = weight of 1 cubic foot of air in receiver at start.

In the accompanying tables the tests given by date were made by the Seniors as part of the regular laboratory exercises; those designated by numbers are taken from the thesis of Messrs. Putnam and Sweetser. Although the observations are not sufficiently numerous to justify the final establishment of new equations, they still permit of one or two interesting deductions.

When the pressure in the receiver was more than twice the atmospheric pressure, a condition fulfilled in all these tests, Fliegner found that the pressure in the orifice was always the same propor-

tionate part of the pressure in the receiver. The present observations not only bear out this statement, but seem to show that there is a different ratio for each orifice.

If the results are plotted with the average receiver pressure (P_3 average) as abscissæ and pounds of air per second (G) as ordinates, it is possible to give a close approximation to the results by a series of straight lines, one for each orifice, converging at the origin. A general expression for the results is, then, of the form $G = C.P.$ (1). The thermodynamic equation for the adiabatic flow of air through an orifice is

$$G = A\sqrt{\frac{2g}{R}}\ \frac{\kappa}{\kappa - 1}\left[\left(\frac{P_4}{P_3}\right)^{\frac{2}{\kappa}} - \left(\frac{P_4}{P_3}\right)^{\frac{\kappa+1}{\kappa}}\right]^{\frac{1}{2}}\frac{P_3}{\sqrt{T_3}}.$$

A = area of orifice in square inches.
κ = 1.405 the ratio of the specific heats.
R = 53.22.
T = absolute temperature.
P = absolute pressure per square inch.

The above equation can be made to represent the flow where the expansion is not quite adiabatic nor frictionless, as shown by Zeuner, by writing it in the form

$$G = A\sqrt{\frac{2g}{R}}\cdot\frac{\kappa}{\kappa - 1}\left[\left(\frac{P_4}{P_3}\right)^{\frac{2}{n}} - \left(\frac{P_4}{P_3}\right)^{\frac{n+1}{n}}\right]^{\frac{1}{2}}\frac{P_3}{\sqrt{T_3}} \quad \ldots\ (2)$$

where $n < \kappa$ and to be determined by experiment. Equation (2) has the form

$$G = \frac{\text{area} \times k_a}{\sqrt{T_3}}\ P_3 \quad \ldots\ (3)$$

By comparing equations (3) and (1), it is evident that the constant (C) embraces the area of the orifice, the temperature at which the experiments were made and a certain constant (k_a) dependent upon the size of the orifice.

As all the results may thus be represented by equation (3), it would be easier to determine the value of (k_a) from a plot if the effect

of the varying temperature were eliminated. The value of (G) has, therefore, been corrected to 32° F. by means of the equation

$$G_0 = G \frac{\sqrt{T_s}\,\text{average}}{\sqrt{492.7}}$$

It is hoped in the near future that enough data will be collected on different orifices to finally establish the values of the constants in the above equations.

FLOW OF AIR THROUGH AN ORIFICE.

Diameter of orifice, 0.1890 inch.

No. or date of test.	Barometer.	Initial pressure in receiver. (Abs.)	Initial temperature in receiver. (Abs.)	Initial pressure in reservoir. (Abs.)	Initial temperature in reservoir. (Abs.)	Final pressure in reservoir. (Abs.)	Final temperature in reservoir. (Abs.)	Final pressure in receiver. (Abs.)	Final temperature in receiver. (Abs.)	Average pressure in receiver. (Abs.)	Average temperature in receiver. (Abs.)	Average pressure in orifice. (Abs.)	Duration of test in seconds.
		P_0.	T_0.	P_1.	T_1.	P_2.	T_2.	P_3 final.	T_3 final.	P_3 average.	T_3 average.	P_4.	
Mar. 12	14.49	14.49	501.6	255.5	498.5	140.5	497.6	54.3	503.9	53.4	507.8	31.3	596.4
Mar. 15	14.61	14.61	499.2	545.6	495.8	355.6	493.2	80.7	499.9	80.6	506.5	48.3	570.0
Mar. 14	14.64	14.64	495.2	447.6	495.6	223.6	495.9	95.0	497.7	94.8	500.1	57.2	660.0
Mar. 12	14.47	14.47	509 3	507.5	503.5	211.5	499 4	123.4	507.1	123.5	514.8	72.7	656.0
Mar. 15	14.61	14.61	496.3	805.6	493.2	524.6	489.5	131.1	497.0	129.6	505.5	76.9	600.0
No. 1	14.93	37.5	499.7	592.9	503.0	533.9	503.5	38.0	504.2	39 2	503.1	23.0	599.75
No. 2	14.93	63.2	501.7	682.9	502.1	592.9	503.0	66.4	505.7	64.6	504.2	37.7	601.75
No. 3	14.93	77.0	521.0	822.9	503.5	682.9	501.1	88.2	507.1	89.3	512.7	52.0	599.75
No. 4	14.75	117.8	502.1	451.7	505.8	289.7	502.6	113.3	505.5	113.7	504.6	65.5	600.25
No. 5	14.76	136.3	505.5	1672.	506.9	1453.	505 8	141.5	504.8	139 4	506.0	80.1	599.5
No. 6	14.76	141.4	509.3	1978.	512.7	1672.	506.9	165.7	505.7	163.6	509.4	93.0	600.0
No. 7	14.76	14.76	512.9	2509.	521.7	1966.	510.7	189 3	508.9	189.2	520.4	107.5	600.25
No. 8	14.75	183.1	503.5	790.7	508.7	449.7	501.5	213.7	507.5	214.0	509.1	122.1	602.0
No. 9	14.75	173.8	508.0	1217.	515.0	781.7	505.5	239.3	508.0	239.2	512.5	136 4	600.5
No. 10	14.75	14.75	504.9	2310.	513.6	1639.	500.3	263.7	502 4	264.4	514.3	156.8	599.75
No. 11	14.75	14.75	511.8	1403.	512.3	830.7	500.8	287.9	508 2	288.7	516.8	164.1	600.25
No. 12	14.75	14.75	514.5	2219.	523.1	1395.	508.4	313.7	509.4	315.6	521.9	179.6	600.5

FLOW OF AIR THROUGH AN ORIFICE.

Diameter of orifice, 0.1890 inch. — *Concluded.*

No. or date of test.	Weight of 1 cu. ft. of air under conditions P_0 and T_0.	Specific volume of air under conditions P_1 and 32° F.	Weight of 1 cu. ft. of air under conditions P_1 and T_1.	Specific volume of air under conditions P_2 and 32° F.	Weight of 1 cu ft. of air under conditions P_2 and T_2.	Weight of 1 cu. ft. of air under conditions P_3 and T_3.	Lbs. of air through orifice per second, under conditions P_3 average, and T_3 average.	Lbs. of air through orifice per second, under conditions P_0 average, and 32° F.	Ratio of pressure in orifice to pressure in receiver.
	w_0.	v_1.	w_1.	v_2.	w_2.	w_3.	G.	G_0.	$P_4 \div P_3$.
Mar. 12	.0782	.6941	1.424	....	0.8183	.2915	.03525	.03578	.5863
Mar. 15	.0792	.3290	3.021	.5060	1.974	4369	.06445	.06534	.5991
Mar. 14	.0800	.4030	2.485	.7966	1.247	.5164	.06501	.06549	.6037
Mar. 12	.0771	.3543	3.317	.8477	1.164	.6584	.08329	.08513	.5888
Mar. 15	.0797	.2219	4.492	.3436	2.929	.7137	.08457	.08561	.5937
No. 1	.....	.....	.....	....	.....	....	.0270	.0273	.5867
No. 2	.....	.....	.....	....	.....	....	.0396	.0401	.5836
No. 3	.....	.....	.....	....	.....	....	.0582	.0594	.5822
No. 4	.....	.....	.....	....	.....	....	.0711	.0719	.5760
No. 5	.....	.....	.....	....	.....	....	.0994	.1007	.5745
No. 6	.....	.....	.....	....	.....	....	.118	.120	.5685
No. 7	.....	.....	.....	....	.....	....	.138	.142	.5682
No. 8	.....	.....	.....	....	.....	....	.137	.139	.5692
No. 9	.....	.....	.....	....	.....	....	.158	.161	.5702
No. 10	.....	.....	.....	....	.....	....	.164	.167	.5929
No. 11	.....	.....	.....	....	.....	....	.187	.191	.5685
No. 12	.....	.....	.....	....	.....	....	.227	.234	.5691

FLOW OF AIR THROUGH AN ORIFICE.

Diameter of orifice, 0.2515 inch.

No. or date of test.	Barometer.	Initial pressure in receiver. (Abs.)	Initial temperature in receiver. (Abs.)	Initial pressure in reservoir. (Abs.)	Initial temperature in reservoir. (Abs.)	Final pressure in reservoir. (Abs.)	Final temperature in reservoir. (Abs.)	Final pressure in receiver. (Abs.)	Final temperature in receiver. (Abs.)	Average pressure in receiver. (Abs.)	Average temperature in receiver. (Abs.)	Average pressure in orifice. (Abs.)	Duration of test in seconds.
		P_0.	T_0.	P_1.	T_1.	P_2.	T_2.	P_3 final.	T_3 final.	P_3 average.	T_3 average.	P_4.	
Feb. 28	14.78	14.78	496.7	713.8	497.6	564.8	493.6	48.7	494.1	48.9	499.1	25.0	600.0
Feb. 25	14.69	14.69	495.2	469.7	499.9	281 7	499.9	53.6	496 7	53.6	500 7	27.9	705.0
Mar. 4	14.67	14.67	501.7	739.7	501.7	552.7	501.7	54.5	501.0	53.8	505.9	28.0	660.0
Feb. 28	14 78	14.78	496.7	554 8	487.1	355.8	483.9	62.9	489 5	63.0	495.8	33.0	600.0
Mar. 5	14.51	14 51	509.4	1346.5	509.4	1139.5	497.2	65 4	496.1	64 4	502 1	33.9	600.0
Mar. 1	14.76	14.76	506.4	1229.	506.2	844 8	500.3	113.3	499.7	113.2	508.5	59.6	600.0
Feb. 26	14.60	14.60	505 1	1068.	505.1	672.6	503.5	113.0	499 7	113.2	508.7	59.2	623.4
Mar. 5	14.46	14.46	497.9	1150.	496.3	756.4	495.4	112.3	499.2	113.3	505.3	59.6	600.0
Feb. 26	14 47	14.47	504.8	669.5	504.8	161.5	505.1	164 4	507.5	167.1	519.1	88.7	525.0
No. 13	14 72	35.5	496.7	324.7	500.3	228.7	501.7	37.8	504.2	37.7	501.2	19.4	599.75
No. 14	14.72	60.7	494.9	489.7	503.1	324.7	500.3	62.9	503.5	63.0	501.7	31.6	600.25
No. 15	14.84	81.2	535.4	260.8	514.5	103.8	511.8	86 6	525 6	87 0	530.0	43.4	393.75
No. 16	14.58	14.58	506.4	1014.6	506.6	624.6	499.0	114.1	504.8	113 5	512.1	56.9	600.0
No. 17	14.72	160.7	497.4	922.7	499.7	479.7	495.4	164.0	502.4	164.7	501.9	79.4	600.0
No. 18	14.73	88.5	494.3	929 7	500.8	332.7	491.6	188.2	499.9	189 0	504 0	96.1	600.0
No. 19	14.73	14.73	495.0	945.7	509.4	211.7	495.0	208.2	511.1	213 6	523.1	109.1	642.25
No. 20	14.72	14.72	507.1	1783.	518.6	922.7	499.7	263.7	504.6	264 5	517.3	126.3	600 0
No. 21	14.73	14.73	512.7	1985.	514.5	019 7	493 8	288.7	498 6	289 8	513.0	147.0	600.5
No. 22	14.76	14.76	510.7	1472.	509.6	385 8	507.3	313 8	505.3	314 1	517.5	159.6	600.0

FLOW OF AIR THROUGH AN ORIFICE.

Diameter of orifice, 0.2515 inch. — *Concluded.*

No. or date of test.	Weight of 1 cu. ft. of air under conditions P_0 and T_0	Specific volume of air under conditions P_1 and 32° F.	Weight of 1 cu. ft. of air under conditions P_1 and T_1.	Specific volume of air under conditions P_2 and 32° F.	Weight of 1 cu. ft. of air under conditions P_2 and T_2.	Weight of 1 cu. ft. of air under conditions P_3 and T_3.	Lbs. of air through orifice per second, under conditions P_3 average, and T_3 average.	Lbs. of air through orifice per second, under conditions P_3 average, and 32° F.	Ratio of pressure in orifice to pressure in receiver.
	w_0.	v_1.	w_1.	v_2.	w_2.	w_3.	G.	G_0.	$P_4 \div P_3$.
Feb. 28	.0805	.2513	3.923	.3178	3.141	.2667	.05297	.05331	.5122
Feb. 25	.0803	.3835	2.570	.6314	1.086	.2920	.05800	.05847	.5205
Mar. 4	.0791	.2423	4.053	.3247	3.025	.2944	.06315	.06399	.5204
Feb. 28	.0805	.3235	3.127	.5057	2.013	.3477	.07298	.07320	.5238
Mar. 5	.0771	.1325	7.300	.1564	6.337	.3567	.05973	.06030	.5264
Mar. 1	.0789	.1453	6.622	.2116	4.655	.6135	.1245	.1265	.5265
Feb. 26	.0782	.1668	5.848	.2667	3.669	.6119	.1365	.1387	.5318
Mar. 5	.0786	.1548	6.414	.2368	4.200	.6087	.1450	.1469	.5260
Feb. 26	.0776	.2679	3.643	1.1280	0.8648	.8766	.1975	.2027	.5308
No. 13	.....	.....	.....	.....	.....	.....	.0422	.0426	.5591
No. 14	.....	.....	.....	.....	.....	.....	.0715	.0721	.5016
No. 15	.....	.....	.....	.....	.....	.....	.116	.120	.4989
No. 16	.....	.....	.....	.....	.....	.....	.134	.137	.5013
No. 17	.....	.....	.....	.....	.....	.....	.199	.201	.4821
No. 18	.....	.....	.....	.....	.....	.....	.230	.233	.5085
No. 19	.....	.....	.....	.....	.....	.....	.250	.258	.5108
No. 20	.....	.....	.....	.....	.....	.....	.275	.282	.4775
No. 21	.....	.....	.....	.....	.....	.....	.345	.352	.5072
No. 22	.....	.....	.....	.....	.....	.....	.375	.384	.5081

FLOW OF AIR THROUGH AN ORIFICE. Diameter of orifice = 0.3753 inch.

Number.		Barometer. (Lbs. per square inch.)	Initial pressure in receiver. (Abs.) P_0.	Initial temperature in receiver. (Abs.) T_0.	Initial pressure in reservoir. (Abs.) P_1.	Initial temperature in reservoir. (Abs.) T_1.	Final pressure in reservoir. (Abs.) P_2.	Final temperature in reservoir. (Abs.) T_2.	Final pressure in receiver. (Abs.) P_3 final.	Final temperature in receiver. (Abs.) T_3 final.	Average pressure in receiver. (Abs.) P_3 average.	Average temperature in receiver. (Abs.) T_3 average.	Average pressure in orifice. (Abs.) P_4.	Duration of test in seconds.	Lbs. of air through orifice per second, under conditions P_3 average, and T_3 average. G.	Lbs. of air through orifice per second under conditions P_3 average and 32° F. G_0.	Ratio of pressure in orifice to pressure in receiver. $P_4 \div P_3$.
23		14.93	37.3	499.7	996.9	499.9	871.9	499.0	38.0	501.5	38.5	501.9	19.6	299.75	.113	.114	.5091
24		14.93	50.2	501.3	1165.9	498.5	980.9	496.3	63.1	501.3	63.5	503.0	31.1	300.0	.162	.164	.4898
25		14.93	88.4	502.8	1434.9	500.8	1150.9	496.1	88.4	500.4	88.8	502.2	42.8	300.0	.240	.242	.4819
26		14.82	98.7	515.9	624.8	499.5	287.8	491.8	112.1	504.0	112.8	509.4	55.8	300.5	.285	.290	.4948
27		14.93	142.7	532.8	1991.9	506.7	1404.9	495.6	165.0	502.4	165.0	513.8	77.5	300.75	.463	.473	.4697
28		14.82	178.5	539.2	1667.8	510.5	664.9	489.3	213.9	500.6	214.7	509.8	105.2	420.25	.565	.575	.4900
29		14.84	92.2	513.2	999.8	514.8	302.9	494.7	255.8	521.3	263.2	533.4	123.9	212.5	.678	.706	.4707
30		14.84	14.8	530.3	2284.8	528.5	977.8	501.3	313.8	517.7	313.9	534.5	147.3	299.5	.850	.885	.4693

FLOW OF AIR THROUGH AN ORIFICE. Diameter of orifice = 0.4993 inch.

Number.	Barometer. (Lbs. per square inch.)	Initial pressure in receiver. (Abs.)	Initial temperature in receiver. (Abs.)	Initial pressure in reservoir. (Abs.)	Initial temperature in reservoir. (Abs.)	Final pressure in reservoir. (Abs.)	Final temperature in reservoir. (Abs.)	Final pressure in receiver. (Abs.)	Final temperature in receiver. (Abs.)	Average pressure in receiver. (Abs.)	Average temperature in receiver. (Abs.)	Average pressure in orifice. (Abs.)	Duration of test in seconds.	Lbs. of air through orifice per second, under conditions P_3 average, and T_3 average.	Lbs. of air through orifice per second, under conditions P_3 average, and 32° F.	Ratio of pressure in orifice to pressure in receiver.
		P_0.	T_0.	P_1.	T_1.	P_2	T_2.	P_3 final.	T_3 final.	P_3 average.	T_3 average.	P_4.		G.	G_0.	$P_4 \div P_3$.
31	14.69	34.8	496.3	525.7	496.1	328.7	492 7	37.8	499.9	37.8	499.7	19.9	299.75	.173	.174	.5265
32	14.69	59.5	502.4	851.7	498.5	515.7	490 7	62.9	498.6	62 7	500.6	32.8	300.0	.296	.298	.5231
33	14.69	81 3	506.4	1312.	500.1	837.7	489.6	88.0	495.4	88.5	500.8	45.7	299.75	.406	.409	.5164
34	14.69	109.0	528.0	1962.	527.5	1305.	494.7	113.3	495.2	113.3	506.9	58.4	300.25	.559	.567	.5154
35	14.63	49.7	507.5	1044.	505.1	420.6	490 4	163.5	509.3	163.7	520.6	87.5	180.25	.780	.802	.5346
36	14.69	135.7	542.6	2164.	512.3	1309.	492 9	214.9	500.3	215.6	519.3	109.9	180.0	1.08	1.11	.5099
37	14.63	235.1	547.2	1950.	533.4	1005.	494 0	263.9	505.5	263.9	523.1	135.6	179.5	1.16	1.20	.5137
38	14 47	248.5	550.1	1632.	516.3	529.5	487.8	313.5	513.0	312 5	528.7	160.0	180.75	1.49	1.54	.5119

FLOW OF AIR THROUGH AN ORIFICE. Diameter of orifice = 0.6333 inch.

No.	Barometer. (Lbs. per square inch.)	Initial pressure in receiver. (Abs.) P_0.	Initial temperature in receiver. (Abs.) T_0.	Initial pressure in reservoir. (Abs.) P_1.	Initial temperature in reservoir. (Abs.) T_1.	Final pressure in reservoir. (Abs.) P_2.	Final temperature in reservoir. (Abs.) T_2.	Final pressure in receiver. (Abs.) P_3 final.	Final temperature in receiver. (Abs.) T_3 final.	Average pressure in receiver. (Abs.) P_3 average.	Average temperature in receiver. (Abs.) T_3 average.	Average pressure in orifice. (Abs.) P_4	Duration of test in seconds.	Lbs. of air through orifice per second, under conditions P_3 average, and T_3 average. G.	Lbs. of air through orifice per second, under conditions P_3 average, and 32° F. G_0.	Ratio of pressure in orifice, to pressure in receiver. $P_4 \div P_3$.
39	14.69	14.69	518.3	604.7	506.9	275.7	498.5	37.8	507.1	37.9	509.3	20.0	209.75	.270	.274	.5277
40	14.80	46.8	522.4	953.8	510.2	121.8	489.6	61.1	503.9	62.5	504.6	33.1	480.5	.462	.470	.5295
41	14.69	14.69	518.4	1395.	516.6	587.7	496.1	88.2	502.4	88.2	513.4	47.5	299.75	.634	.647	.5385
42	14.69	14.69	508.5	1364.	507.6	343.7	491.1	113.3	496.1	113.9	508.9	60.6	300.5	.827	.840	.5321
43	14.67	14.67	508.5	1056.	510.9	255.7	493.9	151.4	500.3	160.9	523.5	85.0	152.25	1.17	1.21	.5282
44	14.67	14.67	523.1	2403.	526.9	1009.7	494.5	213.7	500.3	214.6	520.1	111.9	.....	1.62	1.66	.5314
45	14.74	14.74	512.0	2092.	513.6	486.7	489.3	253.7	497.6	261.3	517.0	136.9	181.75	2.00	2.05	.5240
46	14.67	14.67	522.9	2305.	520.1	438.7	490.2	293.7	498.1	300.2	522.2	162.2	173.0	2.38	2.45	.5247

HIRN TESTS.

The object of these tests is to show the interchange of heat between the steam and the walls of the cylinder during the different parts of the stroke.

A complete description of the manner of conducting such tests, together with the thermodynamic equations used in calculating the results, will be found in the TECHNOLOGY QUARTERLY, Vol. IX, pp. 43 to 50.

The tests here given form a part of a series which have been made on a 9″ – 16″ – 24″ x 30″ triple expansion engine of the Corliss type, made by the E. P. Allis Company.

The report of tests No. I to IV will be found in the TECHNOLOGY QUARTERLY, Vol. IX, and of tests V to XII in Vol. XIII.

These four tests were made with the engine running as a compound, the low pressure cylinder being cut out.

The dimensions of the engine are as follows:

High Pressure Cylinder.

Dia. of piston = 8.99″. Dia. of piston rod = 2.19″. Stroke = 30″.
Piston displacement: H. E. = 1.102 cu. ft.; C. E. = 1.037 cu. ft.
Clearance in % of P. D.: H. E. = 8.83; C. E. = 9.76.
Engine constant: H. E. = .004809; C. E. = .004524.

Intermediate Pressure Cylinder.

Dia. of piston = 16.01″. Dia. of piston rod = 2.19″. Stroke = 30″.
Piston displacement: H. E. = 3.495 cu. ft.; C. E. = 3.430 cu. ft.
Clearance in % P. D.: H. E. = 10.4; C. E. = 10.9.
Engine constant: H. E. = .01525; C. E. = .01497.

Low Pressure Cylinder.

Dia. of piston = 24.063″. Dia. of piston rod = 2.16″. Stroke = 30″.
Piston displacement: H. E. = 7.894 cu. ft.; C. E. = 7.831 cu. ft.
Clearance in % P. D.: H. E. = 12.18; C. E. = 12.27.
Engine constant: H. E. = .0345; C. E. = .03417.

Test Number.	XIII.	XIV.	XV.	XVI.
Duration of test, minutes	60	60	60	60
Total number of revolutions	5,193	5,192	5,027	5,042
Revolutions per minute	86 55	86 53	83.78	84 03
Steam consumption during test, pounds:				
Passing through cylinders	757.5	744 0	1085.0	1057.5
Condensation in h. p. jacket	46.6	45.5	47.2	49.6
in receiver jacket	74 4	67.0	91.0	92.6
in i. p. jacket	63 8	61 6	73.3	72.1
Total	942 3	918.1	1296 5	1271.8
Condensing water for test, pounds	21,345	20,574	28,973	30,768
Priming, by calorimeter	.8%	.7%	1.1%	1.0%
Temperature, Fahrenheit:				
Condensed steam	71.2	71.5	76.4	74.9
Condensing water, cold	46.4	46.3	46.1	46.1
Condensing water, hot	84 6	86.3	85.6	83.0
Pressure of the atmosphere, by the barometer, pounds per square inch	14.79	14 80	14.78	14.79
Boiler pressure, pounds per square inch, absolute	134.8	134.8	133 5	133.5
Vacuum in condenser, inches of mercury	25.86	25.59	25 61	25 59
Events of the stroke, per cent.:				
High-pressure cylinder —				
Cut-off, crank end	10.4	10 3	22.9	22.5
head end	8 5	8 4	23.6	22.2
Release, both ends	100 0	100.0	100.0	100.0
Compression, crank end	7.0	7.0	7.0	7.0
head end	9.0	9.0	9 0	9.0
Intermediate-pressure cylinder —				
Cut-off, crank end	28.0	28 0	21.0	20.5
head end	27.0	27.0	20 0	20.5
Release, both ends	100.0	100.0	100.0	100.0
Compression, crank end	7.0	10.0	7.0	10.0
head end	7.0	10 0	7 0	10.0
Absolute pressures in the cylinder, pounds per square inch:				
High-pressure cylinder —				
Cut-off, crank end	127.8	123.8	123.3	123.3
head end	122 8	120.3	119.7	120.6
Release, crank end	27 1	26 6	41.3	41.9
head end	22 8	22 6	39 3	38.0
Compression, crank end	27 6	25.5	44 7	44.6
head end	26.8	26 3	44 5	43.6
Admission, crank end	42.6	45.0	66.9	67.6
head end	53 8	55.3	93.7	90.0

Test Number.	XIII.	XIV.	XV.	XVI.
Intermediate-pressure cylinder —				
Cut-off, crank end	19.9	20.3	36.0	36.8
head end	20.1	20.6	35.4	35.4
Release, crank end	7.1	6.4	10.3	10.3
head end	6.5	6.3	8.9	9.0
Compression, crank end	2.4	2.5	3.6	3.2
head end	2.5	2.6	2.8	2.7
Admission, crank end	5.6	5.6	7.5	7.5
head end	7.2	7.2	7.8	7.8
Heat equivalents of external work, B. T. U. from areas on indicator diagram to line of absolute vacuum:				
High-pressure cylinder —				
During admission, $A\,W_a$, crank end	2.73	2.64	5.86	5.71
head end	2.25	2.33	6.22	5.89
During expansion, $A\,W_b$, crank end	8.87	8.92	9.90	9.67
head end	8.04	8.11	9.52	9.43
During exhaust, $A\,W_c$, crank end	4.54	4.62	7.53	7.28
head end	4.47	4.51	7.50	7.34
During compres'n $A\,W_d$, crank end	0.58	0.55	0.92	0.83
head end	0.74	0.68	1.38	1.11
Intermediate-pressure cylinder —				
During admission, $A\,W_a$, crank end	4.07	4.11	5.41	5.25
head end	4.09	4.10	5.10	5.15
During expansion, $A\,W_b$, crank end	4.98	4.98	8.78	8.78
head end	5.05	5.02	8.49	8.33
During exhaust, $A\,W_c$, crank end	1.51	1.64	2.17	2.25
head end	1.61	1.54	1.78	1.83
During compres'n, $A\,W_d$, crank end	0.17	0.18	0.30	0.23
head end	0.31	0.26	0.34	0.38
Quality of the steam in the cylinder. At admission and at compression the steam was assumed to be dry and saturated:				
High-pressure cylinder —				
At cut-off x_1	.656	.651	.740	.746
At release x_2	.850	.847	.889	.910
Intermediate-pressure cylinder —				
At cut-off x_1	.856	.889	.820	.856
At release x_2	.898	.859	.846	.882

Test Number.	XIII.	XIV.	XV.	XVI.
Interchanges of heat between the steam and the walls of the cylinders in B. T. U. Quantities affected by the positive sign are absorbed by the cylinder walls; quantities affected by the negative sign are yielded by the walls:				
High-pressure cylinder —				
Brought in by steam . Q	86.2	84.7	127.3	123.8
During admission . . Q_a	26 2	26 0	28.1	26.9
During expansion . . Q_b	−18.4	−18.5	−21.7	−22.8
During exhaust . . Q_c	−10.3	−10.0	−9.6	−7.3
During compression . Q_d	0.6	0 5	1.0	0.8
Supplied by jacket . . Q_f	3 9	3 8	4.0	4.2
Lost by radiation . . Q_e	1.8	1.8	1 8	1.8
First intermediate receiver —				
Supplied by jacket . . Q_{fR}	6.2	5.6	7.8	7.9
Lost by radiation . . Q_{eR}	1.3	1.3	1.3	1.3
Intermediate-pressure cylinder —				
Brought in by steam . Q'	87.2	85 0	128 8	125.7
During admission . . Q'_a	14 3	11.1	23 8	20.1
During expansion . . Q'_b	−6.7	−1 6	−8 5	−8.5
During exhaust . . . Q'_c	−10.1	−11 8	−18.8	−19.3
During compression . Q'_d	0.2	0 3	0.3	0 3
Supplied by jacket . . Q'_f	5.3	5.1	6.3	6.1
Lost by radiation . . Q'_e	3.0	3.0	3 0	3.0
Total loss by radiation:				
By preliminary test . . ΣQ_e	6.1	6.1	6.1	6.1
By equation	8.8	4.0	8.1	6.5
Power and economy:				
Heat equivalents of works per stroke:				
High-pressure cylinder AW	5.90	5.91	7.10	7.19
Int.-pressure cylinder AW'	7.21	7.21	11.37	11.79
Totals	13.11	13.12	18.47	18.98
Total heat furnished by jackets . .	15.3	14 4	18.1	18.3
Distribution of work:				
High-pressure cylinder	1.00	1.00	1.00	1.00
Intermediate-pressure cylinder . .	1.22	1.22	1.64	1.60
Total horse-power	53 57	53 53	75.01	73.22
Steam per horse-power per hour . .	17.6	17.2	17.3	17.4
B. T. U. per horse-power per minute .	305.0	298 0	300.9	302 3
B. T. U. per horse-power per minute, 2 pounds absolute	302.7	295.4	299.6	300.8

Engine Tests.

The tests made on the Triple Expansion Engine run as a compound, the low pressure cylinder being cut out, show the economy of this engine when running under the following conditions:

(1) No jackets on the cylinders and none of the heating surface of the reheater used, the boiler pressure being approximately 100 pounds per square inch by the gauge.

(2) The same conditions as in (1), with the exception of the boiler pressure, which was approximately 120 pounds per square inch by the gauge.

The dimensions of this engine are given in connection with the Hirn tests. A description of the reheater has also been given in the Technology Quarterly, Vol. XI.

The Tandem Compound Engine has the high pressure cylinder only jacketed, and a coil of pipe is used to reheat the steam in the receiver. The tests show the economy of this engine when running under the following conditions:

(1) No jackets used on high pressure cylinder and coil not used in the receiver, the boiler pressure being approximately 100 pounds per square inch by the gauge.

(2) Jackets used on the high pressure cylinder and coil used in the receiver, the boiler pressure being approximately 120 pounds per square inch by the gauge.

The dimensions of this engine are:

	High.	Low.
Diameter of piston, inches	11	19
Diameter of piston rod, inches	1.63	2.13
Stroke, inches		15

All the tests were of 60 minutes' duration, indicator cards being taken at 5-minute intervals.

The plots, Figures 2 to 5, show the heat consumption per horse-power per minute reduced to 2 pounds absolute; one plot for each engine showing the variation of the heat consumption with the change of cut-off on the high pressure cylinder; the remaining plots showing the variation of the heat consumption with the indicated horse-power reduced to 2 pounds absolute.

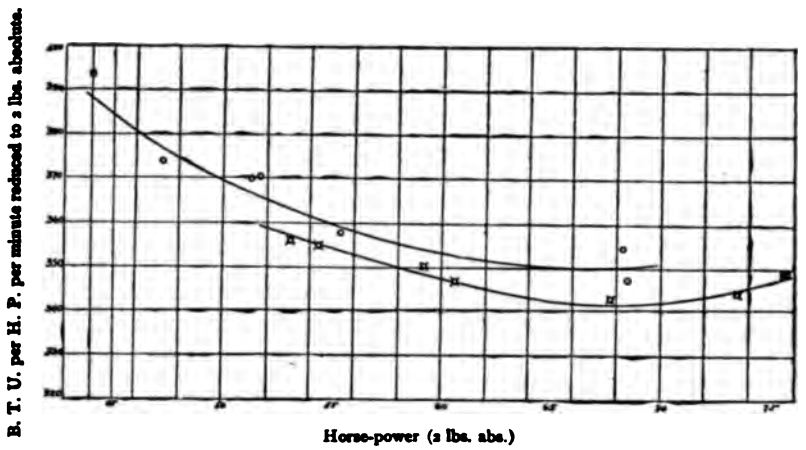

FIG. 2. — RESULTS OF TESTS ON A TRIPLE EXPANSION ENGINE RUN AS A COMPOUND, LOW-PRESSURE CYLINDER CUT OUT.

No jackets used on cylinder or on reheater. Upper curve, 100 lbs. boiler pressure; lower curve, 120 lbs.

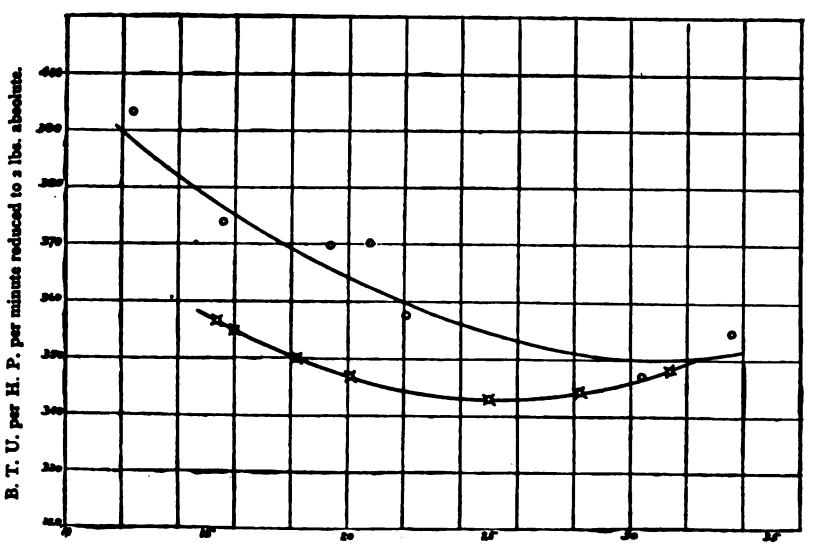

FIG. 3. — RESULTS OF TESTS ON TRIPLE EXPANSION ENGINE RUN AS A COMPOUND, LOW-PRESSURE CYLINDER CUT OUT.

No jackets used on cylinders or reheater. Upper curve, 100 lbs. boiler pressure; lower curve, 120 lbs.

TESTS ON A TRIPLE EXPANSION ENGINE. (Low-pressure cylinder cut out.)

Figures 2 and 3.

Date. 1901.	Horse-power, total. Corrected to 2 lbs. abs.	Steam per horse-power per hour.	Steam through cylinders per hour. (Lbs.)	Revolutions per minute.	Boiler pressure by gauge.	Pressure in first receiver by gauge.	Vacuum in condenser by mercury column. (Inches.)	Barometer. (Inches.)	Barometer. (Lbs. per sq. inch.)
Mar. 26	42 0	22.5	917	85.0	99.3	1.2	24.5	29.6	14.5
Mar. 29	47.3	20.9	981	85.3	99 8	2 0	25.2	29.6	14.5
Mar. 22	51.3	21.0	1,053	83.7	100.2	4.7	24.9	29.9	14.7
May 16	51.7	21.1	1,062	84.3	99.1	5.8	24.9	30.0	14.7
Mar. 19	55.4	19.9	1,099	83.5	99.6	6.3	26.1	30.3	14.9
Apr. 9	68.5	19.2	1,319	83.1	99.7	9.5	25.7	29.6	14.5
May 17	68.3	20.0	1,344	82.7	99.3	11.7	25.1	29.9	14.7
May 10	53.1	19.9	1,047	85 1	118.5	6.1	25.6	30.0	14.7
May 9	54.4	19.9	1,069	85.1	118.2	5.3	25.5	30.0	14.7
May 2	59.2	19.6	1,146	85.1	118.7	8.0	25.0	29 6	14.5
May 7	60.6	19.3	1,163	84.4	118.3	8.3	25.3	29.7	14.6
Apr. 26	67.7	19.3	1,283	83.7	118.9	12.7	25.2	30.2	14.8
Apr. 25	73.5	19.2	1,397	83.4	119.0	11.0	25.1	29.8	14 6
May 6	75.6	19.4	1,455	82.8	118.4	22.5	25.2	29.8	14.6

TESTS ON A TRIPLE EXPANSION ENGINE. (Low-pressure cylinder cut out.) — *Continued.*

High-Pressure Cylinder.

Date. 1901.	Initial pressure.	Per cent. of cut-off.	Pressure at cut-off.	Pressure at release.	Pressure at compression.	Per cent. of steam in cylinders at cut-off.	Per cent. of steam in cylinders at release.	M. E. P., crank end.	M. E. P., head end.	Horse-power. (Indicated.)
Mar. 26	100.5	13.4	88.1	10.1	1.9	55.1	71.9	36.7	31.1	26.9
Mar. 29	102.4	15.7	79.9	13.3	2.3	60.3	77.1	42.9	36.9	31.7
Mar. 22	101.3	19 4	88 8	16.4	4.2	62.6	76.9	44.0	40.6	33.0
May 16	96.1	20.8	85.4	16.1	6.0	63.7	76.3	43.3	39.7	32.6
Mar. 19	101.4	22.1	91.4	18.5	7.9	66.9	78.2	44.8	44.3	34.7
Apr. 9	100.9	30.3	90.6	26.2	10.7	70.1	78.8	51.1	51.5	39.8
May 17	97.6	33.6	89.7	27.0	12.9	73.2	78.5	50.3	50.8	39.0
May 10	113.1	15.4	103.0	15.3	6.4	62.2	76.0	42.7	40.3	32.9
May 9	116.8	16.0	104.9	15.9	6.3	63 5	76.0	45 6	42.0	35.8
May 2	116 9	18.1	108 5	18.7	8.1	65.4	76.5	49.4	44.3	37.1
May 7	117.1	20.0	105.2	19.8	9.3	66 9	77.1	50 7	47.3	38.6
Apr. 26	117.0	24.9	103.2	25.9	14.7	68 7	80.6	52.9	48.6	39.6
Apr. 25	116.7	28.2	105.7	28.9	14.4	70.6	79.0	54.9	54.9	42.7
May 6	117.5	31.9	111.8	33.6	23 0	75.8	81.1	52.4	51.2	40.1

TESTS ON A TRIPLE EXPANSION ENGINE. (Low-pressure cylinder cut out.)—*Concluded.*

INTERMEDIATE PRESSURE CYLINDER USED AS LOW-PRESSURE CYLINDER.

DATE. 1901.	Initial pressure.	Per cent. of cut-off.	Pressure at cut-off.	Pressure at release.	Pressure at compression.	Per cent. of steam in cylinder at cut-off	Per cent. of steam in cylinder at release.	M. E. P. crank end.	M. E. P. head end.	Horse-power. (Indicated.)	B. T. U. per H. P. per minute, actual vacuum.	B. T. U. per H. P. per minute, reduced to 1 lb. absolute.
Mar. 26	.6	38.9	—1 5	—8 8	—11.4	36.1	62.4	5.63	5.19	13.9	403.	394.
Mar. 29	1.5	20.0	—1 9	—8.9	—11.8	34 3	57 3	5.95	5.82	15.2	377.	374.
Mar. 22	3.7	18.8	0.1	—8.2	—11.6	34.7	60.0	7.05	6.56	17.2	376.	370.
May 16	5.0	17.5	2.5	—8.1	—11.4	35.6	60.9	7.35	6.61	17.8	377.	370.
Mar. 19	5.3	18 5	2 4	—7.9	—12.2	38.4	62.4	8.33	7.98	20.6	358.	358.
Apr. 9	9.7	27.5	4.4	—6.3	—12.4	46.2	61.0	11.46	11.49	28.9	347.	347.
May 17	12.1	23.0	6.8	—11.9	—11.3	44.0	62.2	11.72	10.98	28.4	358.	355.
May 10	5.9	18.8	1.3	—7.9	—11.7	37 6	64.6	7.98	7.36	19.7	359.	357.
May 9	4 8	20.3	—0.2	—8.0	—11.7	34 8	60.3	7.92	6.92	19.1	357.	355.
May 2	7.0	19 3	2.5	—7.4	—11.6	37.8	61.8	8.77	7 85	21.4	353.	350.
May 7	7.7	17.5	4 1	—7.8	—11.4	37.8	57.3	9.13	8.00	21.8	347.	347.
Apr. 26	13.2	19.8	5.8	—7.4	—11.2	40 5	56.0	10.92	10.37	26.9	347.	343.
Apr. 25	13.4	20 8	8.3	—5.5	—11.7	42.6	63.1	12.46	11.33	30.0	347.	344.
May 6	22.5	15.5	15.0	—5 3	—11.4	43 2	61.8	14.77	12.97	34.8	351.	349.

TESTS ON A 11″–19″ x 15″ TANDEM COMPOUND ENGINE.

Horse-power.	Steam per H. P. per hour, including jacket steam. (Lbs.)	Steam through cylinders per hour. (Lbs.)	Water by Jackets.		Revolutions per minute.	Boiler pressure by gauge.	Pressure in receiver.	Vacuum in condenser. (Inches of mercury.)	Barometer. (Inches.)	B. T. U. per H. P. per minute actual vacuum.	Horse-power reduced to 2 lbs. absolute.	B. T. U. per H. P per minute, reduced to 2 lbs. absolute.
			High jacket. (Lbs.)	Receiver coil. (Lbs.)								
61.4	25.5	1,568	0	0	243.9	102.7	6.3	24.9	30.11	458	64.0	442
65.3	24.4	1,591	0	0	243.6	103.0	6.1	24.5	29.60	436	67.9	423
74.1	24.1	1,781	0	0	242.7	103.0	8.6	24.6	29.62	431	76.4	420
76.5	23.6	1,806	0	0	239.9	102.0	8.0	25.4	30.12	424	78.0	417
72.9	23.5	1,710	0	0	242.3	103.0	8.1	25.0	29.86	421	74.7	413
75.0	23.4	1,754	0	0	241.8	102.7	9.2	24.5	30.07	417	78.9	401
95.4	22.5	2,149	0	0	239.0	102.3	12.7	24.6	29.30	405	96.9	400
90.7	21.9	1,985	0	0	241.3	102.9	10.4	24.6	29.37	393	92.5	387
93.2	21.9	2,038	0	0	240.2	103.3	12.4	25.0	29.69	393	94.8	388
94.6	22.3	2,113	0	0	240.6	102.8	13.0	25.0	29.97	401	96.9	393
92.1	22.7	2,093	0	0	240.1	103.1	12.7	25.0	30.30	406	95.2	397
107.2	21.4	2,297	0	0	236.6	101.3	15.1	25.1	29.94	385	109.0	380
104.6	20.9	2,192	0	0	241.0	102.4	14.1	25 0	29.72	376	106.2	372
106.7	20.9	2,233	0	0	238.3	103.0	14.5	25.0	29.58	376	108.0	373
111.9	21.0	2,354	0	0	236.7	102.9	17.3	24.6	30.15	376	115.4	368
113.3	20.7	2,342	0	0	236.4	102.6	16.6	24.8	29.51	371	114.8	368
120.9	21.2	2,567	0	0	234.8	103.0	19.0	24.9	30.07	380	123.6	375
127.6	20.8	2,651	0	0	232.1	102.7	21.8	24.6	29.50	373	129.6	369
138.6	20.8	2,893	0	0	231.1	102.0	25.0	25.1	30.05	374	140.7	371
55.4	26.4	1,386	46.6	29.4	243.4	123.8	4.2	24.9	29.69	471	57.2	458
73.7	22.9	1,617	38.8	34.5	244.0	122.0	7.3	25.6	30.17	410	74.9	405
84.6	21.9	1,780	33.3	37.2	243.4	121.2	9.9	24.5	29 59	390	85.9	387
86.4	22.1	1,821	46.0	37.0	242.0	121.2	10.6	25.1	30.00	393	88.5	386
91.5	21.1	1,847	46.1	35.5	243.8	121.9	11.7	25.7	30.18	377	92.6	374
108.4	20.9	2,177	43.7	45.3	240.8	121.5	15.2	25.2	29.77	374	109.7	370
111.9	20.9	2,254	44.3	42.7	240.6	121.5	16.6	24.8	27.70	373	113.9	369
129 8	20.1	2,523	41.6	42.8	236.0	124.6	21.4	25.4	30.04	360	131.0	358
132.9	20.5	2,603	49.4	72.6	237.7	121.3	21.4	25.0	30.00	366	135.2	361
129.4	20.3	2,543	47.0	44.2	238.6	120.9	20.2	24.9	30.13	363	132.1	358
131.4	20.3	2,576	46.1	49.4	238.2	124.4	20.9	25.3	30.02	364	133.0	361
137.3	20.1	2,675	38.4	48.5	237.3	124.0	23.4	25.1	30.04	360	139.3	356
142.9	19.9	2,763	36.6	47.4	239.1	123.9	24.5	25.9	29.97	357	143.9	355
132.1	20.8	2,655	34.1	49.9	231.1	103.0	23.8	24.5	29.97	369	135.6	363

TESTS ON A 11"-19" × 15" TANDEM COMPOUND ENGINE. — *Continued.*

HIGH-PRESSURE CYLINDER.

DATE.	Initial pressure.	Per cent. of cut-off.	Pressure at cut-off.	Pressure at release.	Pressure at compression.	Per cent. of steam in cylinder at cut-off.	Per cent. of steam in cylinder at release.	M. E. P. Crank end.	M. E. P. Head end.	Horse-power.
Mar. 25	92.3	11.0	68.3	18.9	16.1	49.5	67.9	14.9	15.5	26.4
Mar. 26	93.1	11.4	68.2	19.9	16.7	49.0	68.2	15.6	16.4	27.8
Apr. 9	95.2	12.5	71.8	20.7	19.7	53.2	68.5	17.0	18.2	30.4
Feb. 28	95.3	14.3	74.5	23.0	33.8	52.7	68.2	18.8	20.9	33.9
Mar. 22	96.0	14.7	71.9	22.2	19.0	54.9	70.7	19.4	20.6	34.5
Mar. 8	96.7	16.0	69.0	21.0	20.5	54.9	70.9	18.9	21.5	34.8
Mar. 11	97.0	20 1	76.2	28.7	24.4	56.0	72.8	23.6	26.9	43.0
Mar. 28	101.0	20.3	76.7	27.1	18.6	61.1	74.9	23.4	26.6	43.0
Apr. 1	98.0	20.5	75.7	25.8	19.7	59.2	72.8	23.1	24.1	40.4
Mar. 18	97.2	21.3	74.3	28.1	24.6	58.0	73.6	23.7	25 8	42.4
Mar. 19	98.0	21.6	73.0	28 5	22.0	57.9	72.3	23.0	25.8	41.7
Mar. 4	98.3	24.5	82.9	30.4	29.6	63.9	74.3	25.6	31.1	47.8
Mar. 15	101.3	26.6	74.6	30.5	24.4	65.5	76.5	27.1	30.0	49.0
Mar. 29	100.4	27.3	76.9	31.7	27.7	66.0	76.3	27.6	29.8	48.7
Mar. 7	100.4	28.0	77.3	33.8	31.3	64.4	77.7	28.5	31.4	50.5
Mar. 5	98.7	29.8	73.3	34.9	30.9	64.4	78.8	28.6	31.9	50.9
Apr. 2	101.5	35.1	75.7	37.3	31.9	64.9	73.5	28.8	33.9	52.5
Apr. 4	102.8	38.5	79.3	40.4	31.5	73.0	79.8	30.7	35.6	54.8
May 16	100,6	48.0	75.2	44.2	35.7	77.6	81.6	34.1	37.8	59.2
May 13	114.6	5.8	86.8	17.2	7.7	51.6	67.9	13.7	13.4	23.5
Apr. 29	113.1	9.1	86.3	20.1	13.0	52.9	69.9	18.2	17.1	30.7
May 2	116.3	13.7	83.4	24.6	21.3	56 3	71.9	23.0	22.0	39.0
May 9	114.3	14.9	83.5	26.1	20.9	58.0	72.3	20.3	22.8	37.1
Apr. 26	115.3	15.4	86.7	26.7	24.6	59.0	73.1	21.2	23.3	38.6
May 6	117.5	19.7	87.3	32.8	25.9	54.6	86.9	26.2	28.7	47.0
May 7	117.3	21.7	86.6	32.2	27.4	61.2	73.4	26,8	30.5	49.2
Apr. 12	122.4	25.4	90.1	39.9	35.8	63.1	81.6	31.8	34.2	55.5
Apr. 22	119 4	26.8	92.9	40.3	39.5	65.2	81.0	33.1	35.8	58.3
Apr. 23	120.9	27.0	94.7	39.5	32.5	67.2	77.4	30.5	34.9	55.6
Apr. 15	121.2	28.5	92.2	38.8	36.6	67.4	75.3	31.2	36.8	57.7
Apr. 16	120.8	28.8	92.1	40.9	35.0	66.3	77.7	32.2	36.5	58.1
May 14	121.5	34.3	92.4	42.4	33.3	73.1	78.1	33.2	38.7	61.2
Apr. 11	101.3	41.1	78.6	41.6	37.6	75.1	80,6	30,1	36.0	54.5

TESTS ON A 11"-19" x 15" TANDEM COMPOUND ENGINE. — *Concluded.*

LOW-PRESSURE CYLINDER.

DATE.	Initial pressure.	Per cent. of cut-off.	Pressure at cut-off.	Pressure at release.	Pressure at compression.	Per cent. of steam in cylinder at cut-off.	Per cent. of steam in cylinder at release.	M. E. P. Crank end.	M. E. P. Head end.	Horse-power.
Mar. 25	5.4	27.5	—0.24	—7.48	—10.7	52.5	60.5	6.7	6.7	35.0
Mar. 26	5.4	"	0.96	—6.45	—10.7	53.3	66.3	7.3	7.1	37.5
Apr. 9	8.6	"	2.14	—5.96	—10.5	52.8	62.8	8.3	8.5	43.7
Feb. 28	...	"	....	....	....	....	....	8.2	8.4	42.5
Mar. 22	6.6	"	0.81	—6.34	—10.8	51.1	63.4	7.6	7.3	38.4
Mar. 8	7.9	"	1.51	—5.9	—10.3	51.6	64.9	7.9	7.7	40.2
Mar. 11	12.4	"	5.23	—4.06	—10.3	51.1	61.9	10.5	10.1	52.4
Mar. 28	10.1	"	3.96	—4.96	—10.5	52.4	62.3	9.4	9.2	47.8
Apr. 1	12.0	"	5.07	—4.16	—10.5	53.9	65.9	10.6	10.1	52.9
Mar. 18	12.1	"	5.20	—4 50	—10.6	53.0	62 7	10.4	10.0	52.1
Mar. 19	12.6	"	4.75	—4.75	—10.2	52.3	62.3	10.1	9.6	50.4
Mar. 4	15.5	"	7.06	—3.46	—10.6	52.6	63.0	11.8	11.8	59.4
Mar. 15	13.5	"	6.00	—3 80	—10.3	52.8	63.9	11.1	10.6	55.6
Mar. 29	14.3	"	7.07	—3.48	—10.4	53.9	63.7	11.6	11.3	58.0
Mar. 7	17.0	"	8.17	—2.76	—10.1	53.6	64.6	12.2	12.2	61.4
Mar. 5	16.5	"	8.24	—2.63	—10.1	53.4	64.6	12.4	12.4	62.3
Apr. 2	19.3	"	10.30	—2.02	—10.0	53.3	62.5	13.7	13.7	68.4
Apr. 4	20.8	"	10.95	—1.02	—10.2	52.2	63.7	14.9	14.6	72.8
May 16	24.8	"	13.55	—0.93	—9 9	52.6	59.5	16.4	15.9	39.1
May 13	3.7	"	—1.51	—7.11	—10.7	52.9	69.1	6.2	6.2	31.9
Apr. 29	7.4	"	1.08	—6.13	—11.4	55.0	70.8	8.5	8.0	43.0
May 2	12.5	"	2.70	—5.95	—10.4	54.5	62.8	8.9	8.7	45.6
May 9	10.3	"	3.57	—5.10	—10.5	56.3	68.1	9.6	9.6	49.3
Apr. 26	12.9	"	4.25	—4.65	—11.3	58.9	72.4	10.2	10.2	52.9
May 6	14.5	"	7.15	—3.11	—10.28	55.8	68.0	12.3	11.7	61.3
May 7	17.6	"	7.95	—2.60	—10.59	56.2	69.1	12.4	12.1	62.7
Apr. 12	20.5	"	11.1	—1.31	—10.9	56.9	68.2	14.9	14.7	74.3
Apr. 22	20.0	"	10.9	—1.16	—10.7	55.0	74.6	15.1	14.4	74.6
Apr. 23	20.1	"	11.2	—1.27	—10.5	56.8	68.3	15.0	14.1	73.8
Apr. 15	20.4	"	11.3	—1.02	—10.5	56.3	68.5	14.7	14.4	73.7
Apr. 16	22.0	"	12.2	0.75	—10.7	56.0	73.8	15.5	15.9	79.2
May 14	24.5	"	12.9	—0.38	—10.3	55.7	66.7	16.4	15.7	40.1
Apr. 11	23.4	"	13.3	—0.30	—10.2	56.7	67.2	16.0	15.6	77.7

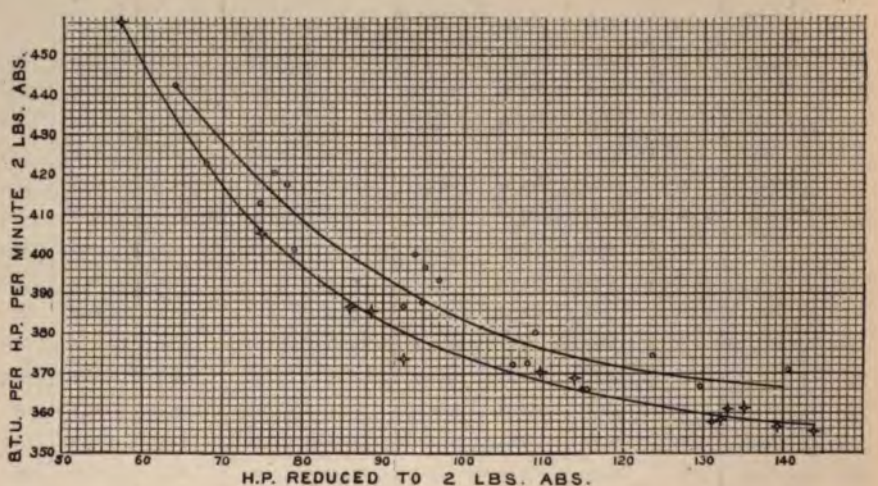

FIG. 4. — RESULTS OF TESTS ON A TANDEM COMPOUND ENGINE.

Upper curve, 100 lbs. boiler pressure (gauge); no jackets used.
Lower curve, 120 lbs. boiler pressure. Jackets on high-pressure cylinder and receiver.

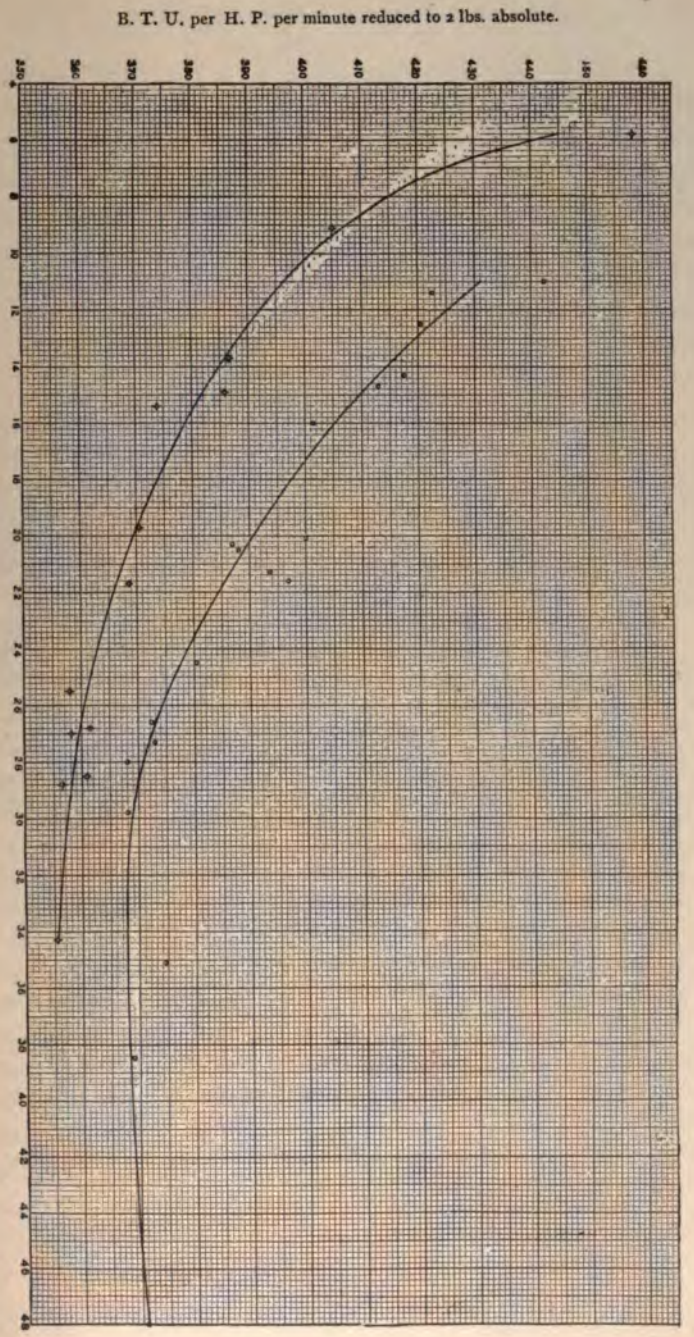

FIG. 5.—RESULTS OF TESTS ON TANDEM COMPOUND ENGINE.

Upper curve, 100 lbs. pressure (gauge), no jackets used. Lower curve, 120 lbs. pressure (gauge), jackets used on high-pressure cylinder and receiver.

Water Ejector Tests.

The following tests were made on a Hancock Ejector, size No. 6, which was fitted with a 1-inch feed pipe and with 2-inch suction and discharge pipes. The feed water was measured by means of a calibrated tank. A small steam pump was used for forcing the water through the ejector. The amount of water discharged was determined by weighing. The pressure heads at entrance, suction, and discharge were found from the readings of Bourdon gauges. The duration of every test was 30 minutes, and observations were taken at 2-minute intervals.

TESTS ON A WATER EJECTOR, 1901.

Number of test.	Entrance head. (Feet.)	Lift at suction. (Feet.)	Lift at discharge. (Feet.)	Water fed in 30 minutes.	Water lifted in 30 minutes.	Work done at entrance. (Foot-pounds per minute.)	Work done at discharge. (Foot-pounds per minute.)	Working efficiency. (Per cent.)
1	112.3	2.7	8.0	6,210	4,320	23,250	1,550	4.0
2	114 8	2.7	7.5	6,330	3,440	24,230	890	3.7
3	117.8	2.8	7.2	6,450	2,000	25,340	670	2.7
4	137.8	3.1	8.6	6,920	6,210	31,780	2,410	7.6
5	143.8	2.9	10.0	6,950	6,330	33,340	2,710	8.1
6	150.6	2.8	9.6	7,110	6,860	35,710	2,830	7.9
7	171.1	3.2	13.9	7,650	6,800	43,600	3,870	8.9
8	171.5	3.0	13.0	7,320	7,460	41,820	3,990	9.5
9	173.6	2.2	11.4	7,510	8,140	43,430	3,660	8.4
10	176.9	2.8	11.8	7,640	8,360	45,020	4,080	9.1
11	185.2	2.8	11.8	7,780	8,570	48,060	4,190	8.7
12	189.1	3.0	12.6	7,860	8,080	49,570	5,190	8.5
13	192.2	3.2	12.6	7,930	8,900	50,760	4,670	9.2
14	192.7	2.1	10.7	7,800	8,470	50,130	3,600	7.2
15	196.3	2.9	14.1	8,230	9,380	54,870	5,320	9.7
16	207.1	2.9	12.7	7,780	7,350	53,740	3,820	7.1
17	228.5	3.3	14.8	8,470	9,820	64,550	5,920	9.2

Tests on a Portable Device for Measuring Water under Pressure.

The apparatus consists of 2 feet of 4-inch steam pipe, to the discharge end of which a flange was screwed. Between this flange and a second one bolted to it was inserted a brass plate containing a standard orifice. The apparatus is shown in Figure 6.

The water was supplied to this orifice pipe through a $2\frac{1}{2}$-inch supply pipe. To determine the pressure acting on the orifice, the orifice pipe was tapped 7 inches behind the brass plate. The pressure was transmitted from this section through suitable piping to a mercury column the scale of which read pounds per square inch.

These pressure readings were corrected for temperature. The water used was measured in a calibrated tank of 250 cubic feet capacity. The coefficients were obtained by substituting in the formula $Q = C\ A\ \sqrt{2gh}$, where (Q) is the cubic feet per second, (C) is the coefficient of discharge, and (A) is the area of orifice in square feet (.003595), $(g) = 32.2$, and (h) is the head as calculated from the pressure, velocity head being negligible.

The temperature of the water varied between 16° and 20° Centigrade.

TESTS ON A DEVICE FOR MEASURING WATER UNDER PRESSURE.

Duration of test. (Minutes.)	Cubic feet of water during test.	Cubic feet of water per second.	Pressure. (Lbs. per sq. inch.)	Head as calculated from pressure.	Coefficient of discharge.
30	144.1	.0801	9.2	21.25	.602
30	188.2	.1045	15.68	36.21	.602
30	207.7	.1154	19.10	44.15	.602
30	208.2	.1157	19.31	44.62	.600
20	160.2	.1335	26.13	60.39	.595
20	169.4	.1411	28.56	65.98	.603
20	176.7	.1472	29.89	69.08	.600
25	228.4	.1523	33.76	78.63	.598
24	228.8	.1589	36.24	83.76	.602
20	194.7	.1622	37.59	86.80	.604
20	210.2	.1752	44.04	101.7	.602
18	193.6	.1792	46.12	106.6	.602
20	216.4	.1803	46.39	107.3	.604
18	213.0	.1972	55.62	128.5	.603

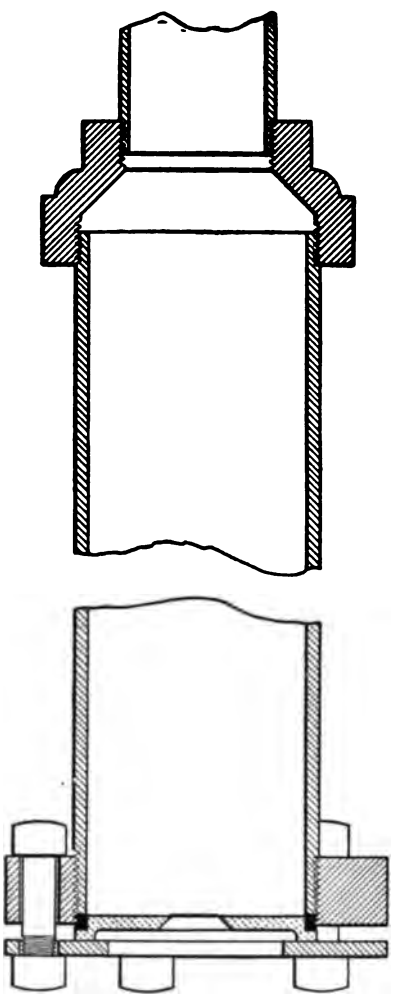

FIG. 6. — PORTABLE DEVICE FOR MEASURING WATER UNDER PRESSURE.

Number of test.	Diameter of cross section. (Ins.)	Distance between jaws. (Ins.)	Gauged length. (Ins.)	Elastic limit. (In.-lbs.)	Outside fiber stress at elastic limit. (Lbs. per sq. in.)	Maximum twisting moment. (In.-lbs.)	Apparent outside fiber stress as calculated from maximum twisting moment. (Lbs. per sq. in.)	Limits of loads for calculating shearing modulus of elasticity. (In.-lbs.)	Angle of twist for difference of loads used in calculating shearing modulus of elasticity.	Shearing modulus of elasticity. (Lbs. per sq. in.)	Number of turns between jaws at fracture.	Turns per foot between jaws at fracture.
1	1.75	59.0	30	19,800	18,720	67,140	63,460	3,600—19,800	2° 46′ 50″	11,180,000	10.55	2.15
2	1.75	56.5	30	21,240	20,180	70,660	67,160	1,800—21,240	3° 16′ 10″	11,110,000	10.30	2.19
3	1.75	53.5	30	21,240	20,180	64,170	60,990	1,800—21,240	3° 19′ 30″	11,440,000	10.40	2.33
4	1.75	52.0	30	21,240	20,180	66,105	62,820	1,800—21,240	3° 15′ 40″	11,130,000	9.25	2.13
5	1.75	51.3	30	21,960	20,860	67,680	64,310	1,800— 9,000	1° 11′ 10″	11,330,000	9.00	2.11
6	1.75	48.0	30	21,240	20,180	63,810	60,640	1,800—20,520	3° 7′ 30″	10,920,000	9.58	2.40
7	1.75	49.0	30	20,520	19,550	68,040	64,680	1,800—19,800	3° 0′ 40″	11,160,000	10.07	2.69
8	1.75	56.2	30	21,240	20,180	67,680	64,310	1,800—19,800	2° 58′ 10″	11,320,000	10.81	2.31
9	1.75	54.5	30	21,240	20,180	65,520	62,260	1,800— 9,000	1° 10′ 30″	11,440,000	9.12	2.01
10	1.75	48.5	30	20,520	19,490	68,760	65,350	1,800— 9,000	1° 3′ 0″	12,800,000	8.89	2.20
11	1.75	52.5	30	20,520	19,490	68,750	65,350	1,800—20,520	3° 6′ 50″	11,230,000	11.21	2.56
12	1.75	55.3	30	19,800	18,810	67,590	64,220	1,800—19,800	3° 1′ 30″	11,110,000	11.22	2.44
13	1.75	48.8	30	21,960	20,860	68,940	65,510	1,800—12,600	1° 45′ 0″	10,180,000	8.00	1.97
14	1.75	49.3	30	23,680	21,550	68,850	65,430	1,800—19,800	2° 54′ 40″	11,520,000	....	....
15	1.75	49.3	30	21,960	20,860	67,510	64,150	1,800—21,960	3° 15′ 20″	11,560,000	8.98	2.19
16	1.76	48.6	30	21,960	20,520	69,700	65,090	1,800—21,960	3° 16′ 10″	11,280,000	9.20	2.27
17	1.75	48.5	30	24,120	22,880	68,850	65,430	1,800—19,800	2° 53′ 30″	11,620,000	8.78	2.17

TORSION TESTS ON WROUGHT IRON, ROME BRAND.

Number of test.	Diameter of cross section. (Ins.)	Distance between jaws. (Ins.)	Gauged length. (Ins.)	Elastic limit. (In.-lbs.)	Outside fiber stress at elastic limit. (Lbs. per sq. in.)	Maximum twisting moment. (In.-lbs.)	Apparent outside fiber stress as calculated from maximum twisting moment. (Lbs. per sq. in.)	Limits of loads for calculating shearing modulus of elasticity. (In.-lbs.)	Angle of twist for difference of loads used in calculating shearing modulus of elasticity.	Shearing modulus of elasticity. (Lbs. per sq. in.)	Number of turns between jaws at fracture.	Turns per foot between jaws at fracture.
1	1.78	49.5	30	18,360	16,580	61,200	55,270	1,800—14,400	2° 8′ 40″	10,250,000	8.41	2.04
2	1.75	49.5	30	14,400	13,680	57,600	54,730	1,800—14,400	1° 58′ 10″	11,980,000	7.36	1.75
3	1.75	48.7	30	12,600	11,970	57,960	55,070	1,800—12,600	1° 48′ 50″	11,120,000	8.83	2.14
4	1.74	49.0	30	12,600	12,180	58,500	56,570	1,800—12,600	1° 48′ 0″	9,105,000	7.95	1.95
5	1.77	49.5	30	15,480	14,220	59,400	54,560	1,800—15,480	2° 28′ 0″	9,897,000	7.34	1.78
6	1.75	51.0	30	13,320	12,660	58,860	55,930	1,800— 9,000	1° 10′ 10″	11,490,000	8.11	1.91
7	1.76	49.0	30	13,680	12,780	57,680	53,860	1,800—10,800	1° 27′ 20″	11,730,000	7.03	1.76
8	1.76	49.0	30	14,040	13,110	58,320	54,460	1,800—12,600	1° 47′ 20″	11,010,000	7.74	1.90

Number of test.	Diameter of cross section. (Ins.)	Distance between jaws. (Ins.)	Gauged length. (Ins.)	Elastic limit. (In.-lbs.)	Outside fiber stress at elastic limit. (Lbs. per sq. in.)	Maximum twisting moment. (In.-lbs.)	Apparent outside fiber stress as calculated from maximum twisting moment. (Lbs. per sq. in.)	Limits of loads used in calculation of shearing modulus of elasticity. (In.-lbs.)	Angle of twist for difference of loads used in calculation of shearing modulus of elasticity.	Shearing modulus of elasticity. (Lbs. per sq. in.)	Number of turns between jaws at fracture.	Turns per inch between jaws at fracture.
1	0.3440	11.0	5	310	39,000	610	76,300	10—310	5° 27′ 30″	11,460,000	6.95	0.63
2	0.3440	10.8	5	300	38,000	598	74,800	50—250	3° 40′ 30″	11,340,000	18.32	1.74
3	0.3440	10.8	5	325	41,000	597	74,700	100—325	4° 0′ 0″	11,400,000	10.90	1.01
4	0.3435	10.5	5	325	41,000	625	79,800	100—300	3° 35′ 30″	11,700,000	19.35	1.84
5	0.3434	10.5	5	350	44,000	625	78,600	100—300	3° 36′ 30″	11,600,000	6.62	0.63
6	0.3440	10.5	5	375	47,000	630	77,500	100—350	4° 42′ 0″	11,100,000	17.90	1.70
7	0.3430	10.5	5	325	41,000	645	81,300	100—300	3° 34′ 30″	11,800,000	18.65	1.78
8	0.3435	10.5	5	350	44,000	633	79,500	100—300	3° 51′ 0″	10,700,000	16.22	1.54
9	0.3437	10.4	5	275	34,000	610	76,500	100—275	3° 31′ 30″	11,300,000	21.55	2.07
10	0.3438	11.3	5	300	38,000	603	76,500	100—250	3° 46′ 30″	11,300,000	20.82	1.82
11	0.3435	11.5	5	270	34,000	543	68,100	100—270	3° 6′ 30″	11,400,000	19.81	1.75
12	0.3435	11.5	5	260	33,000	605	76,000	100—260	3° 14′ 30″	10,300,000	20.58	1.79
13	0.3435	11.5	5	230	29,000	595	74,800	100—230	2° 18′ 15″	11,800,000	21.89	1.90
14	0.3436	11.3	5	240	30,000	595	74,700	100—200	1° 57′ 30″	10,700,000	20.58	1.82
15	0.3436	11.3	5	230	29,000	601	75,400	100—230	2° 38′ 30″	10,500,000	19.28	1.71
16	0.3435	10.3	5	370	46,000	617	77,500	100—350	4° 31′ 30″	11,300,000	15.30	1.40
17	0.3435	11.0	5	360	45,000	623	78,300	100—350	4° 31′ 45″	12,000,000	4.33	0.39
18	0.3435	11.0	5	375	47,000	710	76,700	100—335	4° 12′ 20″	11,700,000	7.75	0.74
19	0.3437	10.3	5	410	51,000	625	78,400	100—300	3° 45′ 30″	11,100,000	12.56	1.22
20	0.3438	10.7	5	400	50,000	695	87,100	100—300	3° 33′ 20″	11,800,000	8.58	0.80
21	0.3435	10.5	5	440	55,000	675	84,800	100—300	3° 33′ 40″	11,800,000	10.10	0.96
22	0.3440	10.8	5	375	47,000	662	83,000	100—300	3° 30′ 55″	11,400,000	16.00	1.51
23	0.3437	10.5	5	350	44,000	645	80,700	100—300	3° 48′ 30″	10,900,000	1.48	0.14
24	0.3436	10.5	5	350	44,000	704	95,800	100—300	3° 33′ 35″	11,700,000	18.70	1.78
25	0.3434	10.5	5	375	47,000	610	76,500	100—300	3° 36′ 10″	11,600,000	16.73	1.59
26	0.3430	11.0	5	350	44,000	675	84,900	100—300	3° 31′ 30″	11,900,000	7.06	0.67
27	0.3430	10.3	5	325	40,000	632	78,500	100—300	3° 30′ 15″	10,700,000	5.01	0.46
28	0.3430	10.5	5	350	44,000	660	74,400	100—300	3° 51′ 30″	11,200,000	13.00	1.17
29	0.3430	10.5	5	350	44,000	616	77,700	100—300	3° 46′ 15″	11,100,000	9.16	0.85
30	0.3430	10.5	5	350	44,000	610	77,000	100—300	3° 47′ 15″	11,400,000	5.05	0.48
31	0.3430	10.5	5	350	44,000	595	75,100	100—300	3° 42′ 15″	11,500,000	9.56	0.91
32	0.3430	10.5	5	375	47,000	595	77,000	100—300	3° 40′ 0″	12,000,000	1.30	0.14
33	0.3430	10.5	5	350	44,000	575	72,600	100—300	3° 40′ 15″			
34	0.3430	10.5	5	375	47,000							
35	0.3430	9.0	5	350	44,000							

BEAMS.

TRANSVERSE TESTS ON HARD PINE BEAMS.

Number of test.	Width and depth of specimen. (Ins.)	Distance between supports. (Feet and inches.)	Limits of loads for calculation of modulus of elasticity. (Lbs.)	Deflections for difference of loads used in calculation of modulus of elasticity. (Ins.)	Modulus of elasticity. (Lbs. per sq. in.)	Breaking load. (Lbs.)
693	4 x 12½	13—0	1,000— 7,000	0.4033	1,920,000	18,400
694	4 x 12½	13—0	1,000— 7,000	0.3815	2,030,000	21,780
695	3⅝ x 11½	15—0	1,000— 5,000	0.5252	1,947,000	16,620
697	3 11/16 x 11 11/16	14—0	1,000—10,600	0.9748	1,728,000	18,110
698	4⅛ x 12½	13—6	3,000— 7,000	0.3641	1,540,000	16,210
700	3⅝ x 12½	13—0	500— 6,500	0.4740	1,588,000	10,110
712	4 x 12½	15—0	1,000— 9,000	0.7393	2,147,000	20,410
713	4 x 12	16—0	1,000— 9,000	0.9353	2,330,000	20,100
714	4 x 12	15—0	1,000—11,000	1.0898	1,935,000	17,900
715	4⅛ x 12½	15—0	1,000— 7,000	0.4404	2,394,000	22,600
716	4⅛ x 12⅝	15—0	1,000—15,000	1.2947	1,955,000	22,100

TRANSVERSE TESTS ON HARD PINE BEAMS. — *Concluded.*

Number of test.	Weight of beam. (Lbs.)	Modulus of rupture. (Lbs. per sq. in.)	Maximum intensity of longitudinal shear. (Lbs. per sq. in.)	Manner of failure.	Manner of loading.	Remarks.
693	220	7,260	287	By longitudinal shear.	At centre.	
694	220	8,535	337	By longitudinal shear.	"	Crippled slightly on top also.
695	250	9,115	293	By tension.	"	
697	220	8,175	292	By tension.	"	Two large knots near bottom at middle.
698	215	6,405	244	By tension.	"	
700	200	3,944	160	By tension.	"	
712	230	9,230	316	By longitudinal shear.	"	
713	265	10,330	318	By tension.	"	
714	255	8,450	284	By longitudinal shear.	"	
715	285	10,470	323	By longitudinal shear.	"	Large crack near top.
716	245	9,217	319	By tension.	"	Broke in two; brittle and dry.

TRANSVERSE TESTS ON SPRUCE BEAMS.

Number of test.	Width and depth of specimen. (Ins.)	Distance between supports. (Feet and inches.)	Limits of loads for calculation of modulus of elasticity. (Lbs.)	Deflections for difference of loads used in calculation of modulus of elasticity. (Ins.)	Modulus of elasticity. (Lbs. per sq. in.)	Breaking load. (Lbs.)
696	3 x 10	13—0	2,000— 4,000	0.5875	1,076,000	8,300
699	2 7/8 x 9 13/16	14—0	400— 2,800	0.6528	1,543,000	6,490
701	2 3/4 x 10	13—0	200— 1,600	0.3554	1,359,000	7,360
702	2 3/4 x 10	13—6	600— 3,100	0.6668	1,449,000	5,780
703	5 1/8 x 5 1/8	14—0	400— 2,400	1.5414	1,291,000	4,990
704	5 1/8 x 6	13—6	600— 2,100	1.2579	1,031,000	3,900
705	2 3/4 x 9 3/4	13—6	500— 2,000	0.3089	2,024,000	7,240
706	2 3/4 x 10	13—0	500— 4,000	0.8635	1,335,000	7,200
707	5 1/8 x 6	13—0	400— 3,200	1.5200	1,377,000	5,200
708	2 3/4 x 9 3/4	13—0	500— 3,500	0.8220	1,306,000	7,290
709	2 3/4 x 9 3/4	13—0	500— 3,500	0.6610	1,561,000	9,060
710	2 3/4 x 10	13—0	500— 3,500	0.6480	1,594,000	7,520
711	6 x 12	15—0	1,000— 8,000	0.7253	1,358,000	17,000
717	6 x 12	15—0	1,000— 6,000	0.5376	1,308,000	12,400
718	5 3/4 x 12	15—0	1,000—10,000	0.9688	1,363,000	17,150
719	6 x 12	14—0	3,000—11,000	0.8289	1,103,000	17,100
691	4 x 12	19—0	1,000— 2,500	0.4350	1,487,000	9,460
692	2 5/8 x 10	13—0	200— 1,400	0.3110	1,271,000	5,920

TRANSVERSE TESTS ON SPRUCE BEAMS. — ***Concluded.***

Number of test.	Weight of beam. (Lbs.)	Modulus of rupture. (Lbs. per sq. in.)	Maximum intensity of longitudinal shear. (Lbs. per sq. in.)	Manner of failure.	Manner of loading.	Remarks.
696	100	3,770	210	.....	At centre.	Buckling prevented breaking.
699	90	5,800	173	By tension.	"	
701	90	6,310	203	By tension.	"	
702	85	5,145	160	By tension.	"	
703	110	6,270	110	By tension.	"	
704	105	4,695	89	By tension.	"	
705	85	6,770	205	By tension.	"	
706	90	5,885	190	By tension.	"	
707	100	5,810	113	By tension.	"	Broke in two; dry and brittle.
708	80	6,385	203	By tension.	"	
709	85	7,570	240	By tension.	"	
710	100	6,445	208	By tension.	"	
711	275	5,355	180	By tension.	"	
717	245	3,915	132	By tension.	"	Warped considerably; large crack on one side.
718	230	5,630	190	By crushing on top.	"	Large crack along top corner.
719	245	5,020	180	By crushing on top.	"	
691	220	5,680	150	By tension.	"	
692	80	4,840	156	By tension.	"	

ROPE TESTS. — TENSION TESTS ON 3″ MANILA ROPE. (3 strands.)

TESTED OVER CAST IRON THIMBLE, 6″ DIAMETER.

Number of test.	Date.	Number of feet per pound.	Number of turns of one strand per foot.	Condition.	Location of break.	Maximum load.	Average strength. (Lbs.)	Efficiency of knot or splice. (Per cent.)	Kind of knot or splice used.
1	Oct. 18, 1899.	....	....	Splices wet. Centre of rope dry.	At centre.	9,915	9,375	100	Spliced eye at each end.
2	Oct. 18, "	....	....		" "	8,375			
3	Oct. 18, "	....	....		Upper splice.	8,535			
4	Oct. 18, "	....	....		Lower splice.	9,255			
5	Oct. 25, "	....	....		.....	8,035			
6	Nov. 2, "	....	....		At centre.	8,830			
7	Nov. 2, "	....	....		" "	9,895			
8	Nov. 8, "	....	....		" "	9,765			
9	Nov. 8, "	....	....		" "	8,405			
10	Nov. 10, "	....	....		" "	9,210			
11	Nov. 10, "	....	....		" "	12,380			
12	Nov. 27, "	....	....		Lower splice.	13,005			
13	Nov. 27, "	....	....		Upper splice.	12,740			
14	Nov. 20, "	3.53	4.3	Dry.	Middle knot	7,950	5,225	53	Englishman's tie in middle; timber hitch at each end.
15	Nov. 20, "	3.53	4.3	"	" "	4,380			
16	Apr. 2, 1900.	3.53	4.4	"	" "	3,890			
17	Apr. 5, "	3.53	4.4	"	" "	4,675			
18	Nov. 20, 1899.	3.53	4.0	"	" "	3,830	3,740	38	Weaver's knot in middle; timber hitch at each end.
19	Mar. 31, 1900.	3.53	....	"	" "	2,920			
20	Apr. 2, "	3.53	....	"	" "	3,885			
21	Oct. 24, "	3.86	4.0	"	" "	4,265			
22	Oct. 26, "	3.86	4.0	"	" "	3,810			
23	Nov. 20, 1899.	3.53	4.2	"	" "	5,575	4,085	41	Square knot in middle; timber hitch at each end.
24	Mar. 31, 1900.	3.53	4.4	"	" "	3,985			
25	Apr. 2, "	3.53	4.4	"	" "	3,855			
26	Oct. 22, "	3.81	4.0	"	" "	3,740			
27	Oct. 22, "	3.87	4.0	"	" "	3,275			

TENSION TESTS ON 3″ MANILA ROPE. (3 strands.)—*Continued.*

TESTED OVER CAST IRON THIMBLE, 6″ DIAMETER.

Number of test.	Date.	Number of feet per pound.	Number of turns of one strand per foot.	Condition.	Location of break.	Maximum load.	Average strength. (Lbs.)	Efficiency of knot or splice. (Per cent.)	Kind of knot or splice used.
28	Nov. 24, 1900.	3.71	4.3	Dry.	Lower knot.	6,060			
29	Nov. 26, "	3.81	4.0	"	Upper knot.	6,400	6,420	65	Fisherman's bend at each end.
30	Nov. 27, "	3.73	4.3	"	" "	7,205			
31	Dec. 10, "	3.90	4.3	"	Lower knot.	6,010			
32	Nov. 25, 1899.	3.53	...	"	Middle knot.	4,555			
33	Apr. 5, 1900.	3.53	4.4	"	" "	4,505			
34	Apr. 12, "	3.53	4.4	"	" "	3,915	3,930	40	Ordinary tie in middle; timber hitch at each end.
35	Nov. 16, "	3.88	4.4	"	" "	3,250			
36	Nov. 17, "	3.75	4.0	"	" "	3,715			
37	Nov 19, "	3.99	4.0	"	" "	3,635			
38	Dec. 11, 1899.	3.53	4.4	"	" "	4,330			
39	Nov. 7, 1900.	3.83	4.3	"	" "	3,135			
40	Nov. 12, "	3.83	4.3	"	" "	3,915	4,110	42	Figure 8, bend in middle; timber hitch at each end.
41	Nov. 12, "	3.79	4.5	"	" "	4,765			
42	Nov. 12, "	3.75	4.4	"	" "	3,745			
43	Nov. 13, "	3.77	4.3	"	" "	4,770			
44	Dec. 11, 1899.	3.53	4.	"	" "	3,270			
45	Apr. 3, 1900.	3.53	4.4	"	" "	3,165			
46	Apr. 9, "	3.53	4.4	"	" "	3,415	3,260	33	Open hand knot in middle; timber hitch at each end.
47	Apr. 10, "	3.53	4.4	"	" "	3,415			
48	Dec. 12, "	3.88	4.0	"	" "	3,030			
49	Dec. 12, "	3.85	4.0	"	" "	3,310			
50	Dec. 12, 1899.	3.53	4.4	"	" "	4,860			
51	Apr. 10, 1900.	3.53	4.4	"	" "	4,055	4,380	44	Carrick single in middle; timber hitch at each end.
52	Oct. 26, "	3.67	4.2	"	" "	4,210			
53	Oct. 29, "	3.68	4.0	"	" "	4,390			

TENSION TESTS ON 3″ MANILA ROPE. (3 strands.)—*Concluded.*

TESTED OVER CAST IRON THIMBLE, 6″ DIAMETER.

Number of test.	Date.	Number of feet per pound.	Number of turns of one strand per foot.	Condition.	Location of break.	Maximum load.	Average strength. (Lbs.)	Efficiency of knot or splice. (Per cent.)	Kind of knot or splice used.
54	Dec. 18, 1899.	3.53	4.0	Dry.	Upper knot.	4,600			
55	Mar. 10, 1900.	3.53	4.5	"	Lower knot.	6,245			
56	Mar. 20, "	3.53	4.4	"	Upper knot.	3,895	4,450	45	Bowline at each end.
57	Mar. 22, "	3.53	4.6	"	Lower knot.	3,805			
58	Mar. 29, "	3.53	4.3	"	Upper knot.	3,645			
59	Oct. 22, "	3 75	4.0	"	" "	4,505			
60	Dec. 18, 1899.	3.53	4.0	"	Lower knot.	3,810			
61	Dec. 20, "	3.53	4.6	"	" "	4,030			
62	Jan. 10, 1900.	3.53	...	"	Upper knot.	3,355	3,670	37	Flemish loop at each end.
63	Oct. 29, "	3 57	4.3	"	" "	3,735			
64	Nov. 13, "	3.80	4.3	"	Lower knot.	3,420			
65	Jan. 1, "	3.53	4.4	"	" "	9,555			
66	Feb. 24, "	3.90	4.4	"	" "	5,955			
67	Mar. 19, "	3.53	4.4	"	Upper knot.	5,755	6,650	67	Clove hitch at each end.
68	Mar. 28, "	3.53	4.4	"	Lower knot.	6,095			
69	Dec. 17, "	4.07	4.0	"	Upper knot.	5,905			
70	Jan. 5, "	3.53	4.4	"	Lower knot.	6,315			
71	Jan. 10, "	3.52	4.4	"	" "	4,655			
72	Mar. 22, "	3.53	4.5	"	Upper knot.	5,490	5,400	55	Timber hitch at each end.
73	Mar. 27, "	3.53	4.5	"	" "	5,325			
74	Mar. 27, "	3.53	4.5	"	" "	5,555			
75	Dec. 17, "	3.90	4.0	"	" "	5,055			
76	Jan. 10, "	3.52	4.4	"	Lower knot.	5,010			
77	Mar. 10, "	3.53	4.5	"	Upper knot.	7,895	5,950	60	Cat's paw at each end.
78	Mar. 27, "	3.53	4 5	"	Lower knot.	5,385			
79	Mar. 29, "	3.53	4.3	"	" "	5,505			

CEMENT TESTS.

PORTLAND CEMENT.—NEAT CEMENT. (Tension.)

Date of test.	Brand.	Per cent. of water used in mixing.	Time of set.	Breaking strength. (Lbs. per sq. in.)
Oct. 31, 1900.	Saylor's.	25	2 days.	526
Oct. 31, "	"	25	2 "	580
Oct. 26, "	"	25	4 "	575
Oct. 26, "	"	25	4 "	620
Nov. 21, "	"	25	5 "	640
Oct. 29, "	"	25	7 "	708
Oct. 29, "	"	25	7 "	708
Oct. 29, "	"	25	7 "	720
Oct. 29, "	"	25	7 "	780
Oct. 29, "	"	25	7 "	740
Oct. 29, "	"	25	7 "	860
Nov. 3, "	"	25	7 "	815
Nov. 3, "	"	25	7 "	885
Apr. 2, 1901.	"	25	1 year.	1,227
Apr. 2, "	"	25	1 "	1,364
Apr. 2, "	"	25	1 "	1,294
Apr. 1, "	"	25	1 "	1,224
Apr. 1, "	"	25	1 "	1,108
Apr. 1, "	"	25	1 "	1,248
Apr. 1, "	"	25	1 "	1,192
Apr. 1, "	"	25	1 "	1,012
Mar. 30, "	"	25	1 "	1,030
Mar. 30, "	"	25	1 "	1,252
Mar. 30, "	"	25	1 "	1,054
Mar. 26, "	"	25	1 "	1,097
Feb. 9, "	"	25	1 "	1,068
Feb. 9, "	"	25	1 "	1,140
Feb. 9, "	"	25	1 "	1,280
Mar. 28, "	"	25	1 "	1,100
Mar. 28, "	"	25	1 "	1,126
Mar. 28, "	"	25	1 "	1,221
Mar. 28, "	"	25	1 "	1,056
Nov. 22, 1900.	Keystone.	25	3 days.	276
Nov. 22, "	"	25	3 "	298
Nov. 22, "	"	25	3 "	322
Nov. 22, "	"	25	3 "	271
Nov. 22, "	"	25	3 "	301
Nov. 21, "	"	25	4 "	332
Nov. 21, "	"	25	4 "	350
Nov. 21, "	"	25	4 "	348
Nov. 21, "	"	25	4 "	320
Dec. 15, "	"	25	5 "	352
Dec. 15, "	"	25	5 "	368
Dec. 21, "	"	25	6 "	386
Dec. 21, "	"	25	6 "	388
Dec. 22, "	"	25	6 "	380
Dec. 22, "	"	25	6 "	383
Dec. 22, "	"	25	6 "	410
Dec. 22, "	"	25	6 "	436
Dec. 22, "	"	25	6 "	445
Nov. 27, "	"	25	7 "	384
Nov. 27, "	"	25	7 "	390
Nov. 24, "	"	25	7 "	424
Nov. 24, "	"	25	7 "	400
Dec. 22, "	"	25	10 "	448
Dec. 22, "	"	25	10 "	424
Dec. 22, "	"	25	10 "	480
Dec. 22, "	"	25	10 "	520
Dec. 31, "	"	25	16 "	545
Dec. 31, "	"	25	17 "	528
Dec. 31, "	"	25	17 "	544
Apr. 10, 1901.	"	25	2 months.	640
Apr. 10, "	"	25	2 "	672

PORTLAND CEMENT. — NEAT CEMENT. (Compression.)

Date of test.	Brand.	Per cent. of water used in mixing.	Time of set.	Breaking strength. (2" cubes.)
Oct. 31, 1900.	Saylor's.	25	2 days.	15,400
Oct. 31, "	"	25	2 "	15,000
Oct. 31, "	"	25	2 "	14,990
Oct. 31, "	"	25	2 "	16,500
Oct. 26, "	"	25	4 "	16,000
Oct. 26, "	"	25	4 "	16,000
Oct. 29, "	"	25	7 "	24,000
Oct. 29, "	"	25	7 "	23,300
Oct. 29, "	"	25	7 "	23,900
Oct. 29, "	"	25	7 "	24,000
Nov. 1, "	"	25	7 "	23,350
Nov. 3, "	"	25	7 "	23,980
Nov. 3, "	"	25	7 "	24,000
Nov. 3, "	"	25	7 "	23,810
Apr. 2, 1901	"	25	1 year.	42,400
Apr. 2, "	"	25	1 "	44,000
Apr. 2, "	"	25	1 "	49,500
Apr. 1, "	"	25	1 "	46,360
Apr. 1, "	"	25	1 "	47,350
Apr. 1, "	"	25	1 "	46,740
Apr. 1, "	"	25	1 "	46,000
Apr. 1, "	"	25	1 "	46,310
Mar. 30, "	"	25	1 "	47,820
Mar. 30, "	"	25	1 "	47,690
Mar. 30, "	"	25	1 "	45,100
Mar. 30, "	"	25	1 "	46,370
Feb. 9, "	"	25	1 "	42,810
Feb. 9, "	"	25	1 "	42,200
Mar. 28, "	"	25	1 "	45,250
Mar. 28, "	"	25	1 "	49,450
Mar. 28, "	"	25	1 "	42,100
Mar. 28, "	"	25	1 "	42,150
Mar. 28, "	"	25	1 "	43,800
Nov. 21, 1900.	Keystone.	25	2 days.	5,650
Nov. 21, "	"	25	2 "	5,490
Nov. 21, "	"	25	2 "	5,630
Dec. 15, "	"	25	5 "	9,970
Dec. 15, "	"	25	5 "	8,100
Nov. 22, "	"	25	7 "	10,850
Nov. 22, "	"	25	7 "	11,850
Nov. 22, "	"	25	7 "	11,050
Nov. 22, "	"	25	7 "	10,050
Jan. 12, 1901.	"	25	7 "	10,000
Jan. 12, "	"	25	7 "	10,700
Jan. 12, "	"	25	7 "	10,440
Jan. 11, "	"	25	9 "	10,000
Jan. 11, "	"	25	9 "	10,100
Jan. 11, "	"	25	9 "	10,050
Jan. 11, "	"	25	9 "	10,630
Dec. 22, 1900.	"	25	9 "	10,900
Dec. 22, "	"	25	10 "	13,200
Dec. 22, "	"	25	10 "	12,750
Dec. 22, "	"	25	10 "	13,320
Dec. 21, "	"	25	11 "	13,280
Dec. 21, "	"	25	11 "	12,580
Dec. 21, "	"	25	11 "	12,850
Dec. 31, "	"	25	16 "	13,600
Dec. 31, "	"	25	16 "	15,540
Apr. 10, 1901.	"	25	2 months.	18,000
Apr. 10, "	"	25	2 "	18,440
Apr. 10, "	"	25	2 "	16,850

PORTLAND CEMENT. — SAND TESTS. (Tension.)

Date of test.	Brand.	Parts sand to one part cement.	Per cent. of water used in mixing.	Time of set.	Breaking strength. (Lbs. per sq. in.)
Nov. 16, 1900.	Saylor's.	3	12	2 days.	97
Nov. 16, "	"	3	12	2 "	155
Nov. 12, "	"	3	12	3 "	96
Nov. 12, "	"	3	12	3 "	106
Nov. 12, "	"	3	12	3 "	122
Nov. 19, "	"	3	12	5 "	188
Nov. 19, "	"	3	12	5 "	183
Nov. 19, "	"	3	12	5 "	177
Nov. 5, "	"	3	12	5 "	145
Nov. 5, "	"	3	12	5 "	167
Nov. 5, "	"	3	12	5 "	157
Mar. 30, 1901.	"	3	12	1 year.	270
Mar. 30, "	"	3	12	1 "	342
Mar. 30, "	"	3	12	1 "	349
Feb. 9, "	"	3	12	1 "	339
Feb. 9, "	"	3	12	1 "	380
Feb. 9, "	"	3	12	1 "	344
Feb. 9, "	"	3	12	1 "	360
Mar. 28, "	"	3	12	1 "	318
Mar. 28, "	"	3	12	1 "	322
Mar. 28, "	"	3	12	1 "	326
Mar. 28, "	"	3	12	1 "	316
Apr. 16, "	Keystone.	3	12	7 days.	73
Apr. 16, "	"	3	12	7 "	89
Apr. 16, "	"	3	12	7 "	90
Nov. 27, 1900.	"	3	12	7 "	76
Nov. 27, "	"	3	12	7 "	81
Nov. 27, "	"	3	12	7 "	86
Nov. 27, "	"	3	12	7 "	89
Jan. 12, 1901.	"	3	12	8 "	94
Jan. 12, "	"	3	12	8 "	90
Jan. 12, "	"	3	12	8 "	84
Apr. 13, "	"	3	12	9 "	93
Apr. 11, "	"	3	12	14 "	118
Apr. 11, "	"	3	12	14 "	118
Apr. 11, "	"	3	12	14 "	98
Jan. 2, "	"	3	12	16 "	115
Apr. 4, "	"	3	12	3 months.	134
Apr. 4. "	"	3	12	3 "	160
Apr. 4, "	"	3	12	3 "	130
Apr. 4, "	"	3	12	3 "	190

PORTLAND CEMENT. — SAND TESTS. (Compression.)

Date of test.	Brand.	Parts sand to one part cement.	Per cent. of water used in mixing.	Time of set.	Breaking strength. (2" cubes.)
Nov. 16, 1900.	Saylor's.	3	12	2 days.	2,000
Nov. 16, "	"	3	12	2 "	2,100
Nov. 16, "	"	3	12	2 "	2,500
Nov. 16, "	"	3	12	2 "	2,000
Nov. 12, "	"	3	12	3 "	2,400
Nov. 12, "	"	3	12	3 "	2,700
Nov. 12, "	"	3	12	3 "	2,200
Nov. 12, "	"	3	12	3 "	2,850
Nov. 12, "	"	3	12	3 "	2,380
Nov. 12, "	"	3	12	3 "	2,200
Nov. 12, "	"	3	12	3 "	2,750
Nov. 5, "	"	3	12	5 "	5,500
Nov. 5, "	"	3	12	5 "	5,670
Nov. 5, "	"	3	12	5 "	6,350
Nov. 5, "	"	3	12	5 "	5,880
Nov. 5, "	"	3	12	5 "	5,810
Mar. 30, 1901.	"	3	12	1 year.	10,000
Mar. 30, "	"	3	12	1 "	12,000
Mar. 30, "	"	3	12	1 "	14,000
Mar. 28, "	"	3	12	1 "	10,800
Mar. 28, "	"	3	12	1 "	15,700
Mar. 28, "	"	3	12	1 "	12,400
Nov. 27, 1900.	Keystone.	3	12	7 days.	2,800
Nov. 27, "	"	3	12	7 "	2,660
Nov. 27, "	"	3	12	7 "	2,835
Jan. 12, 1901.	"	3	12	8 "	2,000
Jan. 12, "	"	3	12	8 "	2,350
Mar. 28, "	"	3	12	14 "	2,410
Mar. 28, "	"	3	12	14 "	2,730
Mar. 28, "	"	3	12	14 "	3,050
Mar. 28, "	"	3	12	14 "	2,480
Apr. 10, "	"	3	12	2 months.	3,200
Apr. 10, "	"	3	12	2 "	2,800
Apr. 4, "	"	3	12	3 "	3,890
Apr. 4, "	"	3	12	3 "	3,650
Apr. 4, "	"	3	12	3 "	3,810
Apr. 4, "	"	3	12	3 "	3,250

THE PULSOMETER STEAM PUMP.

By JOSEPH C. RILEY.

THE idea of raising water by condensation of steam and then forcing it to a further elevation by the direct pressure of steam on the surface of the water originated with Captain Thomas Savery, who in 1698 patented his celebrated "fire engine." Properly speaking, the device was not an engine, but a sort of pump, the forerunner of the present pulsometer.

It consisted of two closed vessels, supplied with steam through valves at the top, and provided with pipes through which water could be drawn in and discharged. In operating, one vessel was first filled with steam. The steam valve was then closed, and a spray of cold water injected. The vacuum formed caused water to rise through the suction pipe, filling the vessel. The spray cock was then closed and steam let in, pressing upon the surface of the water and forcing it out through the discharge pipe. By aid of a man to operate the valves, a continuous stream could be maintained from the two vessels.

In those days the demand for pumping machinery came almost entirely from the coal mines, where great need was felt for some form of mechanical pump to take the place of manual labor or animal power. At once Savery's engine found a useful field, but its enormous consumption of steam by useless condensation was everywhere against it, and moreover the very limited height to which it could force water made it quite unfit for use in the deeper collieries. Newcomen's atmospheric engine soon provided mechanical power in a more convenient form, and engineers from that time gave their attention to designing pumps of the piston type. Savery's principle was soon abandoned, and no other successful steam-vacuum pump was produced for nearly two hundred years.

In 1872, Charles H. Hall patented the pulsometer in a form which, though it has since been slightly altered, has remained unchanged in

its essential details. Its principle is simply a modification of Savery's original idea, improved in its application by the use of an automatic steam valve in place of valves requiring a man to operate them. It is no longer limited to small lifts, for much higher steam pressures are now available.

A pulsometer of the old style, made under Hall's patents of 1872 and 1881, is shown in section in Figure 1. It consists of a single casting having two pear-shaped chambers, with tapering necks bent toward each other, and surmounted by another casting in which the two passages unite in a common chamber. At the junction is a brass ball, which oscillates with slight rolling motion, thus closing either of the two chambers to the passage of steam from the supply pipe above. Water is drawn in from below, through the suction valves, one of which is shown in section. It is expelled through the passages *E E*, through the discharge valves, and into the triangular space, shown dotted, and finally is delivered through the vertical pipe. A foot valve in a separate casting below the pump prevents return of the water in the suction pipe. *P P* are the pumping chambers. The circular passage, *S*, is in the front part of the casting, and connects with the air chamber, marked *A*. Two small holes, not shown in the cut, pass from beyond the discharge valves back into the pumping chambers. These are the injection tubes. They are located just below the horizontal upper edges of the discharge passages. Into the three small holes near the top of the chambers, air valves are fitted, their purpose being to admit air to the chambers when the pressure within

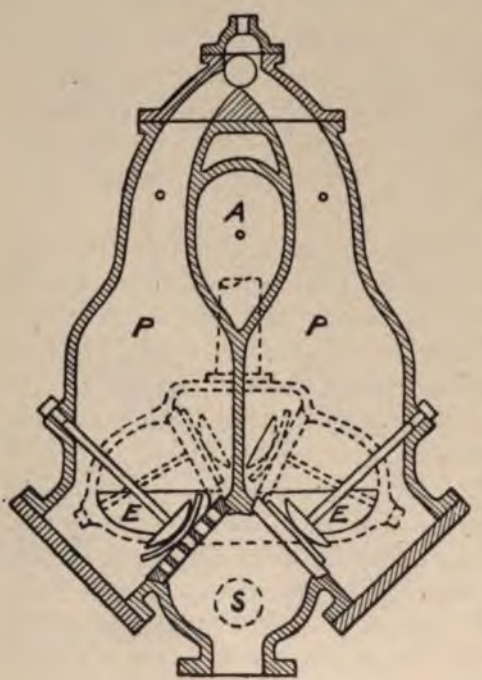

FIG. 1.

is less than that of the atmosphere. The amount which they may open is adjusted by thumb screws.

The operation of the pulsometer is as follows: The ball being at the entrance of the left-hand chamber, and the right-hand being full of water, steam enters, pressing on the surface of the water, and forcing it out through the discharge passage. A rapid condensation of steam occurs from contact with the water and with the walls of the chamber, previously cooled by the water. When the water level has reached the horizontal edge of the discharge passage, a large volume of steam suddenly escapes and is at once condensed by the relatively cold water between the chamber and the discharge valve. The pressure in the chamber quickly decreases; it cannot be sustained by steam from the boiler, for, in accordance with the inventor's first specifications, the steam pipe is small. If now the pressure in the left chamber is equal, or nearly equal, to that in the right, friction caused by the rapid flow of steam past the ball will draw the ball over and close the right-hand chamber. Cut off from further supply, the steam, in contact with water, begins to condense; a jet of cold water from the discharge pipe spurts up through the injection tube, and by breaking into spray against the side of the steam space, completes the condensation. The partial vacuum produced brings water through the suction valve to fill the chamber; but at the same time the air valve admits a little air, which passes up ahead of the water and forms an elastic cushion to prevent the water from striking violently against the steam ball. The air chamber, *A*, is for the purpose of preventing water-hammer in the suction pipe.

In the manner just described, the pump pulsates regularly, steam being condensed, mingling with the water and passing out at the discharge pipe, one chamber pumping while the other is filling, with no external evidence that the pump is working except a slight clicking of the steam valve as it rolls between its seats.

The pulsating action may be further explained by reference to the indicator diagrams of Figure 2. These were taken from a pulsometer like that shown in Figure 1. Crosby indicators with 20-pound springs were used, the cords being pulled simultaneously and uniformly by mechanical means. The indicator pipes entered the three chambers near their highest points. Steam at a gauge pressure of 21 pounds was supplied from a reservoir close at hand. A pressure on the discharge valves of 12.4 pounds was obtained by an actual water column,

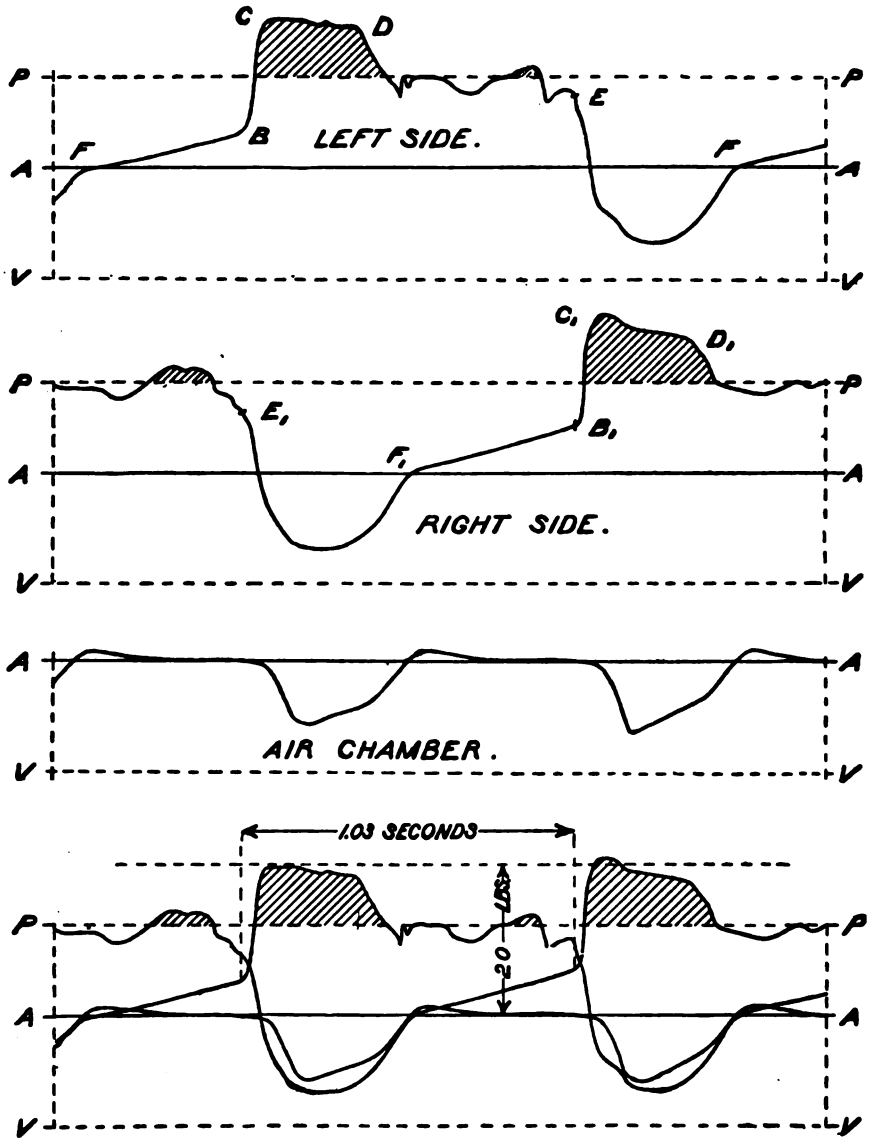

FIG. 2. — INDICATOR DIAGRAMS.

AA, atmospheric line; *PP*, water pressure on discharge valves; *VV*, vacuum line.

not by pumping against a partially closed valve. From the cistern to the suction valves there was a lift of 4 feet; from cistern to steam valve measured 6 feet. The pump was pulsating regularly about once a second, and delivering about 10 cubic feet per minute. The total lift was 33.1 feet.

All of the diagrams are to the same scale. The first three are combined in the fourth. In each diagram, *A A* is the atmospheric line; *V V*, the absolute vacuum line; *P P*, a line showing the water pressure on the discharge valves. In the upper diagram, at *B*, the ball rolls to the right, closing the right side. Steam enters the left chamber, raising the pressure to about 20 pounds at *C*. From *C* to *D*, steam forces the water out of the chamber, but the increase in volume, due to an increasing diameter of the chamber, combined with a more rapid condensation as the water surface spreads out, causes a downward slope of the steam line from *C* to *D*. Meantime, in the right-hand chamber, from E_1 the pressure dropped, by condensation, to below the atmosphere. Water was drawn through the suction valve and air admitted at the air valve until, at F_1 the chamber was nearly filled, or perhaps it is better to say until atmospheric pressure was reached.

Driven by the pressure in the discharge pipe, water continued to be forced back through the right injection tube, compressing the air in the chamber and steadily increasing the pressure from F_1 to B_1. During this time, from *D* to *E*, steam had been escaping from the left-hand chamber into the discharge pipe. The passage of the steam is not uniform, but may be likened to the gulping flow of air into a bottle when filled with water and quickly turned neck downward. This supposition is confirmed by the undulating line drawn by the indicator from below *D* to *E*.

At *E*, the pressure in the left chamber was still a little greater than that in the right at the same instant, but friction of the incoming steam, or the impulse given by it, drew the ball off from its right-hand seat, and closed the left-hand chamber. Thus one pulsation was completed.

It was thought, before taking the diagrams, that the air chamber might play a more important part than proved to be the case. It was found that the air valve of this chamber had to be left open more than either of the other two in order to prevent water-hammer in the suction pipe, for otherwise the supply of air in the chamber was

soon exhausted. This chamber is merely to provide an air cushion for the suction and produce a quiet action of the pump; it is not absolutely necessary — Hall's original pulsometer had none.

Reference to the lowest diagram will show what is happening in all three of the chambers at any instant. The shaded areas, above the discharge pressure line $P\,P$, show when water is being forced through the discharge valves. About one-fourth of the distance across the diagram, from the left, the pressure in the left chamber rose above the discharge pressure. At this moment the pressure in the right chamber fell below the atmosphere. Thus the left pump began to discharge at the instant when the right began to draw its water from the suction pipe. But the left had emptied and steam began to escape before the right was full. This should not be the case. An ideal diagram would show one side discharging while the other is filling, both actions beginning and ending together, and instantly upon their completion the valve should shift and reverse the actions. Delay in moving the valve after the forcing action was completed, produced the great waste of steam between D and E of the upper diagram when steam was blowing through into the discharge pipe, and no pumping at all was done. (The very small shaded area probably represents a redischarge of water which had flowed back into the pumping chamber.) The valve cannot leave its right-hand seat and move toward the left against a great excess of pressure, so that if its motion is to be hastened, the suction period must be shortened and pressure in the chamber which has just filled must increase faster than is shown by the sloping lines $F_1\,B_1$. This might be accomplished by closing the air valve and not allowing any air to enter. The better vacuum thus formed would cause the chamber to fill more quickly, and fill completely with water, and no air being present, the back flow through the injection tube would at once raise the pressure as desired.

But unfortunately such action is impracticable with a steam valve of the ball type. If no air is admitted, the rising water strikes the ball a violent blow and lifts it bodily from its seat, producing very irregular pulsation and sometimes stopping the pumping altogether. Another form of steam valve which is hinged at its top, and swings between its seats, is not subject to this objection, and has been found to give excellent results. Let it be added that the valve of this particular pulsometer was in good condition, and its motion was quite free.

In connection with the time taken to fill a chamber, attention is called to the fact that the indicator, during filling, reached 10 pounds below atmospheric pressure, although the lift was only 4 feet, and the suction pipe was perfectly clear.

The pulsometer from which these diagrams were obtained was tested in January, 1901, at the Massachusetts Institute of Technology. It is known as a No. 4 Pulsometer, of the old style, and was built by the Pulsometer Steam Pump Company, of New York. It has a $\frac{1}{2}$-inch steam pipe, and $2\frac{1}{2}$-inch suction and discharge pipes. The volume of each pumping chamber from steam valve to upper edge of discharge passage is 0.211 cubic feet. Water was fed from a large calibrated tank to a barrel directly underneath the pulsometer, and a constant level maintained in the barrel. The possible error in water measurement was less than 1 per cent.

The discharge pipe was about 3 feet long, having one long sweep bend and leading horizontally into a large tank connected with a 10-inch standpipe. Waste valves on the standpipe made it possible to maintain any desired head with a fluctuation of not more than one-tenth of a foot. Steam was brought from the boiler through an orifice $\frac{5}{16}$ inch in diameter, into a reservoir made of 8-inch pipe, wrapped to prevent condensation. A short piece of $\frac{3}{4}$-inch pipe led from there to the pulsometer, where it was reduced to $\frac{1}{2}$ inch. Especial care was taken to secure perfectly dry steam in the reservoir. Drip cocks on the pipe from the boiler and on the reservoir served to drain what water might collect before starting. Expansion on passing the orifice served to dry, and in some cases to even slightly superheat the steam, as was shown by a thermometer in the reservoir. Dry steam was accordingly assumed in the calculation whenever superheating was not shown.

The quantity of steam used was computed by means of the rise in temperature of the water. Two Centigrade thermometers graduated to tenths of a degree were carefully compared with each other and placed one in the suction and one in the discharge pipe. The readings of one were accepted as read, and those of the other corrected for observed differences in the readings.

The duration of each test was about 20 minutes, but in every case, the pump had been in full operation under constant conditions of lift and steam pressure for at least 10 minutes before beginning the test. The air valves were set to give maximum discharge for each different steam pressure and head on discharge valves. The lift from barrel to

suction valves was 4 feet, and was the same on all the tests. Clear fresh water at a temperature of about 70° was pumped.

Results are given in the following table:

Number of test.	Total lift in feet.	Cubic feet pumped per minute.	Steam in pounds per minute.	Steam pressure by gauge on reservoir.	Excess of steam pressure over water pressure on discharge valves.	Efficiency as a pump.	Pulsations per minute.	Per cent. of full capacity per pulsation.
1	9 6	14.45	3.10	9.9	7.6	.00323	85	80.6
2	9.7	16.84	4.18	15.1	12.7	.00283	100	79.8
3	21 6	8 39	2 68	12 8	5.3	.00486	50	79.6
4	21.5	10 04	2.75	15.3	7 8	.00564	57	83.4
5	21.5	11.53	2 88	17.7	10 2	.00458	62	88.1
6	32.9	10 60	5.18	24 2	11.8	.00479	59	85 3
7	32 9	10 18	4 62	23 0	10 6	.00519	57	84 8
8	46 4	7.10	4.37	23 1	5.0	.00543	48	70.1
9	46 6	9.37	4 70	28 9	10.7	.00669	53	83.7
10	46.7	10.70	5.71	34.0	15.7	.00632	56	90.6
11	60.0	8 42	4.65	32.4	8 3	.00775	49	81 4
12	60.1	9 14	5 21	34.0	9 8	.00755	52	83 3
13	60.2	10.14	5 45	37.5	13 3	.00802	53	90 7
14	72 5	8 52	5.11	38.0	8 5	.00850	53	76.3
15	72 6	9 19	6.03	42.7	13.1	.00779	54	80 6
16	72 6	9 33	6 12	42.8	13 2	.00784	54	81.8
17	72 6	10.02	6.81	46.8	17.3	.00760	54	88.1

It appears that for each discharge head there is a certain most effective steam pressure, which in general is from 8 to 13 pounds higher than the water pressure on the discharge valves. If this is exceeded, irregular pulsation will occur, and if greatly exceeded, steam will blow continuously into the discharge pipe, and the pump will fail to operate. The effect of too slight an excess of steam pressure and

consequent slow pulsation is indicated in the low efficiency of Test 8, caused partly by long contact of the steam with the water, and partly by return of an excessive quantity of water through the injection tubes during the suction periods.

The efficiency shown in these tests is lower than those about to be mentioned; but it must be remembered that the pump is a small one, and that the cards show an imperfect application of the designer's principle, though perhaps as good a one as can be obtained from this pump.

Hartmann and Knoke give results of tests made at Bromberg in 1886, on a pulsometer of Haussmann's patent. This pulsometer had for a steam valve a metal piston moved horizontally from side to side by the difference of steam pressure upon its ends which were connected by small passages to the lower part of the pumping chambers. The size of the pump is not stated.

The results obtained are given in the following table:

Number of test.	Suction in feet.	Total lift.	Cubic feet pumped per minute.	Steam in pounds per minute.	Steam pressure by gauge.	Efficiency as a pump.	Pulsations per minute.	Rise in temperature of water, degrees Fahrenheit.	B. T. U. per minute given up by steam.	B. T. U. necessary to heat water and to pump.
1	4.3	51.2	7.86	3.24	42.6	.00877	26	4 66	3,670	2,300
2	5.7	51.5	8 18	3.41	44.1	.00871	26	2 34	3,860	1,220
3	7.0	51.3	5.41	2.42	44.1	.00807	21	2.16	2,740	750
4	9.0	51.7	7.55	3.60	42.6	.00767	25	4.32	4,070	2,060
5	9.2	51.1	6.41	2.73	44.1	.00845	23	.52	3,090	233
6	10 6	51.6	8.39	4.36	41.2	.00701	30	.63	4,940	364
7	12.6	50.3	10.42	4.53	41.2	.00819	42	3.60	5,130	2,380
8	14.2	51.3	6.56	2 83	44.1	.00838	25	1.26	3,210	540
9	14.4	50.5	11.09	4.97	36 8	.00454	44	2.70	5,620	1,900
10	17.0	49.8	5.64	2.37	42.6	.00837	27	2.70	2,680	970
11	18.7	51.5	6.84	2 57	44.1	.00966	28	2.12	2,910	930

The intention in these tests seems to have been to vary the suction lift and the discharge lift without changing their sum, and

so determine the most advantageous height at which to place the pulsometer in order to secure most efficient action. This is an important question, but it cannot be answered from the results of these tests. In the absence of more complete information concerning the accuracy with which the measurements were made, it is impossible to say what reliance can be placed upon the results. It is certain, however, that the heat accounts do not balance well. They were computed on the assumption that dry steam was supplied, and that the final temperature was 70° F. In these tests, the steam used was measured at the boiler, a method which is inexact at its best.

Tests on a pulsometer with 4-inch suction and delivery pipes were made by students of Stevens Institute, under the direction of Professor Wood, in 1891, and reported to the American Society of Mechanical Engineers. The steam used was calculated from the increase in temperature of the water. The water pumped was measured by a meter. A summary of the tests is given in the following table:

Number of test.	Suction lift in feet.	Discharge lift in feet.	Cubic feet pumped per minute.	Steam in pounds per minute.	Pressure of steam by gauge.	Probable excess of steam pressure over water pressure on discharge valves.	Pulsations per minute.	Efficiency as a pump.
1	12.3	30	36.1	8.98	19	6.0	71	.0120
2	12.3	54	16.6	5.18	30	6 6	60	.0155
3	19.7	54	20.4	8 44	44	20 4	57	.0126
4	19.7	30	22.1	5.67	26	13.1	64	.0138

Of the first two tests with equal suction lifts, the one having the higher discharge lift showed the greater efficiency. Of Tests 1 and 4, with equal discharge lifts, the one having the higher suction lift showed the greater efficiency. Tests 3 and 4 were made with equal suction lifts, but in 3 the discharge lift was higher than in 4, and yet 4 showed the greater efficiency. This was probably due to too large an excess of steam pressure in Test 3.

At an industrial exposition held at Görlitz in 1885, a very large pulsometer was used to supply water for an artificial cascade. This pulsometer, built by a firm of German engineers, was after Hall's pat-

tern, but had an improved form of steam valve, consisting of a tongue of metal suspended at the top and free to oscillate through the small space between the valve seats. This form of valve was mentioned in the discussion of valve action as shown by the diagrams.

The pumping chambers measured 23 inches in diameter at their lower ends, and had each a volume of 3.95 cubic feet, measured from the steam valve to the discharge passage. The discharge pipe was 111 feet long, $8\frac{7}{8}$ inches in diameter, and had several elbows. Two tests made by Eichler gave the following results:

	1	2
Total lift in feet	29.5	29.5
Suction lift in feet	3 3	3.3
Cubic feet pumped per minute	141.3	141.0
Steam used, pounds per minute	11 0	13 8
Steam pressure, pounds per square inch above atmosphere	23 5	26 5
Probable excess of steam pressure over water pressure on discharge valves	13 6	16.6
Pulsations per minute	40	42
Per cent. of full capacity per pulsation	90	85
Foot pounds work done per pound steam	23,700	18,800
Efficiency — assuming dry steam and a discharge temperature of 70°,	.0271	.0215

These performances are considered to be particularly economical ones, and are doubtless due in part to the immense size of the pulsometer, although Eichler ascribed most of the gain in efficiency to the favorable action of his pendulum steam valve. In these tests the lifts were constant. No greater discharge resulted in Test 2 than in Test 1, although steam of higher pressure was used. It is thought that the pressure was too high. Attention is called to the excess of steam pressure over water pressure. Hartmann and Knoke state that this excess should be at least half an atmosphere, and better still, three-quarters or a whole atmosphere. This may be compared with the results obtained at the Massachusetts Institute of Technology.

Mention, at least, should be made of the Grel valve, an arrangement sometimes placed in the neck of a pulsometer above the steam

ball. Its action is analogous to that of an independent cut-off valve on a steam engine; it shuts off the steam before the pumping stroke is completed, allowing the steam to do work by expansion during the remainder of the stroke. This valve is said to effect a saving of over 25 per cent. in the steam consumption.

Regarding the relative efficiency of pulsometers when compared with piston steam pumps, in spite of what the makers claim, actual tests show a very wasteful record for the pulsometers. Eichler's large pulsometer at Görlitz gave the remarkably high efficiency of 2.7 per cent., but a good duplex pump of the same capacity, about 1,000 gallons per minute, may easily return a duty of 28,000,000 foot-pounds per 1,000,000 thermal units, which means an efficiency of 3.6 per cent. The economy of smaller pulsometers is very much less, though of course, they must be compared with the class of piston pumps generally used for handling small quantities, that is, with direct acting piston pumps which operate their own valves, not with duplex pumps.

But notwithstanding its wasteful use of steam, the pulsometer is well qualified to compete with other pumps for some kinds of work. Its entire lack of moving parts or rubbing surfaces is a great advantage where it must stand rough usage, or where the liquid to be pumped contains grit or sand. Equipped with a simpler form of valve in place of the rubber discs, it will successfully pump very thick liquids or semi-fluids, such as heavy syrups, or even liquid mud. It is often used in chemical works and tanneries for pumping corrosive liquids. For temporary work in draining excavations, or in emergencies, such as wrecking operations where a powerful pump must be put at work in the shortest possible time, the pulsometer is peculiarly adapted, since it requires no foundation whatever, but can be slung from a chain and supplied with steam through a flexible hose.

BOSTON, 1901.

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GEOLOGICAL HISTORY OF THE CHARLES RIVER.

BY FREDERICK G. CLAPP.

[Concluded from page 201.]

TERTIARY HISTORY OF THE CHARLES RIVER SYSTEM.

HAVING deciphered the geography of the region included in the present basin of the Charles River as it was at the beginning of the Pleistocene period, let us now endeavor to verify the results obtained by going back to the Tertiary period and showing how the Pleistocene streams could be developed from earlier ones. As this period is more remote and of comparatively long duration, and as the relics of many of the old valleys have long since disappeared, it is obviously impossible to trace in detail the changes during that time. The best that can be done is to show the most probable changes that could bring about Pleistocene conditions.

I have shown that at the beginning of the Pleistocene period the present Charles River was not in existence; but instead, the region was drained by a number of streams of varying importance, coinciding to a considerable degree with the geological structure. The region west of Medway was drained by two main streams flowing south to join the Blackstone in Rhode Island; the Populatic flowed south from Holliston, and also joined the Blackstone, but farther east; the Baggistere had its source near the head of the Populatic, but flowed

FIG. 14. — DUDLEY POND; SITE OF BURIED VALLEY BETWEEN THE SUDBURY AND CHARLES RIVERS.

FIG. 15. — SAND-PLAIN BETWEEN PICKEREL AND JENNINGS' PONDS; SITE OF BURIED VALLEY BETWEEN THE SUDBURY AND CHARLES RIVERS.

in the opposite direction, to the Neponset, which at that time followed approximately its present course to the sea; the Merrimac flowed southeast from Lowell to Boston Bay; the region north of Dedham and east of Needham was drained by an independent stream, probably a branch of the Charles; while the entire area now comprised in the Sudbury and Assabet basins was tributary to the Charles, and thence to Boston Bay.

To attain these conditions complex developments were necessary, although the changes were probably not so momentous as those shown by Professor Crosby to have taken place in the case of the Nashua River.

FIG. 16. — MORSE'S POND; SITE OF BURIED VALLEY BETWEEN THE SUDBURY AND CHARLES RIVERS.

The Charles differs from the Nashua in not having such a strongly marked and simple valley as the latter. Instead, it is a composite of several valleys. While with the Nashua the Tertiary changes were the greatest, in the Charles those of the Pleistocene period are found to be the most important. The Tertiary changes which did occur cannot, however, be neglected here.

When, at the close of the Cretaceous period, the recently formed peneplain was raised gradually out of the sea, its surface consisted of unconsolidated Cretaceous sediments which overspread the whole region, completely burying the underlying solid rocks. Evidently, there was a gradual upward slope inland, and the grade was increased

at the time the land was elevated. Therefore, upon this plain, sloping to the east and south, a drainage system must have been established following the normal seaward slope, and entirely independent of the structure of the underlying rocks. This original drainage system probably resembled more or less closely the present drainage of southern New Jersey. It would be useless to attempt to decipher the courses of these *oldest* streams. The last remnants of their valleys have long since disappeared, and they are as likely as not to have flowed at some points over the tops of our highest hills. Following the laws of development of streams, main trunks were formed into which flowed minor streams, all of which kept continuously at work wearing away the land. Thus, in a comparatively brief geological time, the Cretaceous sediments were entirely removed, and the streams became superimposed upon the pre-Cretaceous rocks of varying hardness, in which for a while they continued their work of erosion.

Remnants of some of the valleys formed in the succeeding epochs can be seen at present in numerous gaps in the highlands, at present unoccupied by large streams. One of these gaps, probably formed in early Tertiary time, is the marked line of valley which the old Middlesex Canal followed from Lowell to Boston, and which is the site of the early Pleistocene Merrimac. This is the most direct route to the sea for the Merrimac, and there is no necessity for supposing that at any time during the Tertiary period it took a different course. Another gap, of less extent, lies between Bear and Doublet hills, west of Waltham, having a minimum elevation of 160 feet, and making a pass two miles wide in the crystalline rocks forming the watershed of the Charles at this point. This pass is in line with a marked depression extending westward from Sudbury. Several miles south of this, across the watershed in the vicinity of Cochituate, is a third gap, which below the 200-foot contour is a mile and a half wide, and, like the one at Waltham, has a minimum elevation of 160 feet, the level of the sand-plain at this point. The topographical map shows that this gap is continued eastward through the present valley of the Charles between Needham and Dedham, and thence along Mother Brook to the Neponset River. Westward it is continued between Nobscot and Green hills to the valley of the Assabet. A fourth line of valley extends eastward from the vicinity of Sherborn through Millis, Walpole and Norwood, crossing the Charles-Neponset water-

shed at the level of the 160-foot sand-plain. The high ridge extending north from Bellingham has been already noted. Both east and west of this are north-south valleys, pointing towards prominent gaps in the southern watershed: one at South Milford, two miles wide between the 300-foot contours; the other east of Bellingham, and a mile wide. Each of these gaps is in a direct line with the corresponding portion of the Charles to the north, and probably marks the site of a Tertiary outlet towards Narragansett Bay. As one coincides exactly, and the other closely, with the outlet at the beginning of the Pleistocene period, the streams occupying them, like the Merrimac, probably did not change their courses greatly during Tertiary time. South of the height of land across Foxsboro, Wrentham and Franklin, all drainage was to the south. The streams which formed these various gaps are the earliest of which any traces remain, and represent that epoch when the Tertiary system of drainage had become firmly established in the pre-Tertiary formations.

Some of the streams of that time, like the Merrimac, and the Milford and Medway branches of the Blackstone, maintained their courses until the Pleistocene period. They flowed across formations of varying hardness, but, being beyond the influence of more powerful neighboring streams, were not diverted from their courses. For instance, the river crossing the Cochituate watershed to the Charles, coming from an area of hard crystalline rocks, crossed the softer formations in Wellesley and Needham, then flowed over the crystalline area east of Needham, reaching the sedimentaries again in Hyde Park (Plate 1, facing page 172). It is possible that this stream may be the lower portion of the Wachusett River[1] discovered by Professor Crosby, who has traced its course as far as the Assabet. The discovery of an ancient river flowing from the Assabet to the sea makes it a reasonable supposition that the two were synchronous, and hence probably the same. This stream, coming from a long distance, and having many tributaries, must have carved out a broad valley, and appropriated the drainage of a considerable area. The upper portion of the Sudbury and its tributaries belonged to this system. The valley of the Sudbury north of Cochituate is certainly very old, and was probably formed at that time. Being tributary to the powerful trunk stream, it could erode its valley rapidly, cutting below the level of the Waltham gap, and beheading

[1] W. O. Crosby: Geological History of the Nashua Valley. TECHNOLOGY QUARTERLY, XII, p. 312.

the stream occupying it. The lower portion of this beheaded stream is represented today by Stony Brook, which has never been of sufficient size to make a large valley. One of its branches, the infantile Charles, flowing northward from Needham through the Boston basin, cut backward toward the south, and on account of its location on the softer rocks, deepened its valley below that of the east-west stream (the possible Wachusett). This river was retarded in its erosion by the crystalline areas across which it flowed, making possible its capture by the Charles. Thus, except for several minor tributary streams, the Tertiary valley between Wellesley and Hyde Park was left dry. The valley northeast of Needham was probably formed by a tributary to the Charles which cut backward from Highlandville along the slate belt to the east.

The other great Tertiary stream draining the area under consideration was the Baggistere, which rose in the vicinity of Holliston, and flowed east as far as Norwood; thence it either maintained its eastward direction to the sea along the southern border of the Blue Hills, or else turned slightly to the north, reaching Boston Bay through the Neponset Valley, along the north side of the range. If it ever flowed on the south side of the Blue Hills it cannot have done so for any great length of time; for, flowing across the crystalline rocks between the Norfolk and Boston basins in the vicinity of Braintree, its down-cutting must have been retarded, giving the drainage of the Boston Basin an opportunity to cut back southward along the sedimentary belt west of the Blue Hills and to capture the Baggistere.

Whether or not such a capture took place, the Neponset Valley, as is shown by its great size, was at an early date occupied by a large stream. The Neponset River, flowing entirely upon the sedimentary rocks, was able to cut back its valley for a considerable distance, the limit probably being reached in the vicinity of Norfolk, where, as indicated by the topography, a tributary of Narragansett Bay had its source. At first the south-flowing streams in this vicinity may have run directly across the crystalline area between the Norfolk and Narragansett basins; but in time they must all have been diverted to the easier outlet through the connecting pass at Wrentham. Thus the Norfolk basin became occupied by two main streams, flowing in opposite directions from the watershed at Norfolk. The minor streams having their sources on the large crystalline area to the north then so adjusted themselves as to take the most direct courses to the

main streams in the basin. It is probable, however, that little adjustment was necessary, as the basins lay directly across their seaward paths.

It certainly does not appear that any simpler sequence of events than those outlined above could have brought about the conditions which existed at the beginning of the Pleistocene period, and undoubtedly the Tertiary changes were much more complex. But we have found that the preglacial streams deduced from present conditions correspond closely with those derived from the most probable development of the Tertiary drainage.

Lake Charles.

At the beginning of the Pleistocene period occurred the great elevation of the land which is regarded as the cause of the great Ice age, during which a mantle of bowlder clay, or till, was spread over the surface of the land. As the till, in most places, makes but a thin covering over the underlying rock, an occurrence of the former is usually a fairly good indication that rock exists at no great depth below. This is not a necessary conclusion, however, for valleys have frequently been found which are filled with till to a considerable depth. And in some cases drumlins lie directly in the path of a preglacial valley or gorge. As examples in this region we have Milton Hill in Milton, and Fairmount in Hyde Park. Either North Hill in Needham or the drumlin just east of Wellesley must also overlie a buried gorge.

With the subsidence of the land at the close of the Glacial epoch came the melting of the ice-sheet and the release of great volumes of water, which collected south of the receding ice-front in glacial lakes. In basins where the preglacial drainage had been to the north, the water-parting on the south naturally formed the southern barrier of the glacial lake. But in the basins of the Upper and Middle Charles the greater part of the preglacial drainage was southward. In these cases, at times when the ice-front rested at narrow portions of the south-sloping valleys, the detritus-laden streams from the ice-sheet formed apron-plains of sand and gravel, which completely closed the valleys and presented an effectual southern barrier to the glacial lake.

Lake Charles, being retained on the south by the frontal plains and the intervening highlands, and on the north by the high ice-front,

necessarily overflowed through the lowest pass in its southern water-parting. As the ice receded northward, lower and lower passes were uncovered in the southern and eastern sides of the basin, serving as successive outlets for the lake, and allowing the water to fall each time to a lower level. Each stage of the lake is characterized by extensive deposits of modified drift, the maximum elevation of each coinciding approximately with the level of the lake during that stage.

Bellingham Stage. — During its history, Lake Charles had twelve distinct outlets, two of which coincided with outlets of glacial Lake Neponset (Plate 4). The stages are less in number than the outlets, however, for during the earlier history of the lake each stage had several outlets at or near the same level. Thus the two outlets in the vicinity of Bellingham and those southeast of Franklin have all an elevation of about 240 to 260 feet, as shown by the contours. The stage of the lake corresponding to these outlets may be called the Bellingham stage.

The shore line of the lake at this time was in the vicinity of the 260-foot contour, and extended up the main valley as far as Milford, and up the valley of Hopping Brook two miles beyond Braggville. Down the valley it extended to near North Bellingham. Bear Hill and several smaller prominences rose as islands in the lake. The greatest depth of water was about 60 feet, in the vicinity of Crimpville. The outlet showing the best developed frontal plain is about half a mile wide, and situated midway between Unionville and Bellingham. At this point the steep and irregular ice-margin can be seen on the north, while in the other direction there is a long gradual slope to the southward. During this stage the water of the lake reached the sea through the Blackstone by way of Abbot's, Peters' and Mill rivers.

South of Franklin, at the margin of the area occupied by the Bellingham stage, and about 80 feet above the level of the water at this time, is a small area of modified drift about a mile and a half long, with an elevation of over 340 feet. This area presumably marks the site of a marginal lakelet, which was formed while the valley to the south was still occupied by ice. It must represent the true beginning of Lake Charles. During the decline of the Ice age such marginal lakelets were numerous, most of them, however, being of small size.

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Stage.

Neponset Stage

RY AND LAKE NEPONSET.
of the drift deposits.)

Wrentham Stage. — Simultaneously with the Bellingham stage was the Wrentham stage, during which the ice in the region east of Franklin was disappearing. In this area there are four outlets, three of which are south of Whiting Pond, and the fourth just south of the Pinnacle. According to the topographical map, these outlets vary in elevation between 240 and 280 feet; but, like the Bellingham and Franklin outlets, they should probably all be referred to a single stage of the lake, the average elevation of which was near the 260-foot contour. The drift deposits show that on the west the shore line extended north to the vicinity of City Mills, and on the east to the southern part of Norfolk. There were several islands, one east of Franklin, a second east of Marsh Pond, a third southeast of City Mills, and two small ones south of Whiting Pond. The best developed deposits, so far as observed, are the Wrentham plains. Whiting, Archer's and Marsh ponds are kettle holes in these plains. The valley of Mill Brook was occupied by a lobe of ice, as is shown by the fact that the deposits referable to the next lower stage extend as far south as Whiting Pond. Plate 4 shows that the northern boundary of the deposits of this stage has a northwest-southeast trend, indicating that this was the direction of the ice-front. The same is true of the deposits formed during all the later history of the lake, showing that the ice disappeared faster from the western than the eastern part of the region.

Charles-Neponset Stage. — The continued recession of the ice during the Bellingham and Wrentham stages finally opened a passage to the east along the north end of the ridge north of Foxboro, and Lake Charles then became confluent with Lake Neponset. Probably about the same time the gap at Medway was opened, and the portion of the lake to the west became connected with the main body of Lake Charles. The development of the Neponset lake had been going on simultaneously with Lake Charles, and the ice had by this time receded far enough north to open the Stoughton outlet, at an elevation of about 200 feet. This, being lower than any hitherto uncovered pass in either lake, became the sole outlet for the confluent lakes. During this stage Lake Charles-Neponset probably occupied its maximum area. The Stoughton outlet must have continued in use for a relatively long time, while the ice was receding from the large area between Norfolk and the northern part of Sherborn in the Charles basin, and between Canton and the Blue Hills in the

Neponset basin. A comparison of these areas (Plate 4) again shows evidence of a more rapid retreat of the ice in the west than the east.

The deposits of this stage extend below the 200-foot contour up the valley of the Upper Charles beyond North Bellingham, along Mine Brook as far as Unionville, and in the valley of Mill Brook into the basin of Whiting Pond. Northward they extend through the pass north of Holliston occupied by the Boston & Albany Railroad, nearly to South Framingham, and east of Sherborn to the vicinity of Farm Pond. The pass west of Snow Hill, in Dover, must have been occupied by a shallow arm connecting the main lake with a bay to the north, as is proved by the deposits of modified drift at this level in the valley of Trout Brook. From the Neponset basin an arm extended north from Norwood, across Westwood to beyond Fox Hill. The presence of 200-foot deposits west and north of Great Blue Hill shows that while this area was covered by water the Monatiquot outlet was still blocked by ice on the east. Between Walpole and South Walpole, on the divide between the Charles and Neponset basins, extensive sand-plains were deposited, blocking the preglacial valley. During this stage the greatest depth of water in the Charles basin was about 100 feet, in the vicinity of Medfield, and in the Neponset basin, nearly 140 feet. Noon, Nason, Paul, Pine and Castle hills, besides many smaller areas, formed islands.

Sudbury-Charles-Neponset Stage. — With the disappearance of the ice from the valley of the Monatiquot River, an outlet was opened along the south side of the Blue Hills, at a level of about 160 feet, allowing the lake to overflow to the east, into Lake Bouvé,[1] which at that time had a level of about 120 feet. During this stage the Charles and Neponset lakes were confluent at two points: first, through a narrow pass, perhaps not over 500 feet wide, between the valley of Mine Brook in Walpole and Stop River in Medfield; and second, at Dedham, where the pass was nearly two miles wide. Lake Charles was also confluent with Lake Cochituate and Lake Sudbury. The water overflowing through the Monatiquot was not only that due to the melting of ice in the Charles-Neponset region, but also that of a large area to the west. At this time the ice-front in the Nashua Valley probably stood in the vicinity of Clinton, and the outlet of Lake Nashua was through the pass at South Clinton into the valley

[1] A. W. Grabau: Lake Bouvé. Occasional Papers, Bos. Soc. Nat. Hist., Vol. IV, Pt. 3, pp. 554–600.

of the Assabet River and thence to Lake Sudbury.[1] Thus the drainage of the entire area within the watersheds of lakes Nashua, Sudbury, Charles and Neponset was at this stage tributary to Lake Bouvé.

The plains at this stage of the confluent lakes are by far the best developed of any stage. The broad deposits in Medfield, Millis and Medway, as well as those in Wellesley, Needham and West Roxbury, were formed at this time. In Newton they are developed as far north as the Boston & Albany Railroad. Extending from Brighton westward along the line of the railroad into Weston is a well-developed ice-contact slope, which marks the northern limit of the lake at this stage. West of Needham and Sherborn the plains extend through Wellesley, Natick and Framingham, across the Cochituate water-parting to the valley of the Sudbury, where an extensive series of the same general elevation is found, extending even down the valley of the Concord River into Bedford and Billerica. Between Brighton and Hyde Park there is a satisfactory eastern land barrier for the lake (Plate 4), but the absence of such a barrier in the northern part of Newton, and again in Dedham, together with the characteristic ice-margins found in those places, indicates that while on the west the ice had retreated as far north as Billerica, it still occupied Boston Bay and a large part of the Boston Basin.

Lake Shawmut. — When the region directly north of the Blue Hills was finally uncovered, the passes in East Milton and West Quincy were opened, and the lake fell to still lower levels, first to about 70 feet, and later to about 50, corresponding to successive levels of Lake Bouvé. Still later the water stood at about 20 feet above the sea. Plains of these elevations are found in Newton, Waltham, Watertown, Boston, and in the valley of the Mystic River. To these lower stages of the combined lakes, entirely within the Boston Basin, Professor Crosby has given the name Lake Shawmut. To this body of water the lakes occupying the valleys of the Concord and Shawsheen rivers were tributary along the line of the Middlesex Canal and the ancient course of the Merrimac. When the ice finally retreated from the land on the southern side of Boston Bay, Lake Shawmut fell to sea level and disappeared.

Postglacial Development of the Charles River.

During the time when the ice was retreating from the region and the glacial lakes were falling successively to lower and lower levels,

[1] W. O. Crosby: Geological History of the Nashua Valley, *l. c.* p. 318.

new streams and drainage systems were gradually developing upon the land surface recently uncovered. The drift deposits had so changed the character of the topography, however, that the streams rarely resumed their former courses, the principal factor in reversing the drainage in the Upper and Middle Charles being the formation of the apron-plains which blocked the south-sloping valleys, and thus formed a new water-parting, north of which all drainage must be northward. As Lake Charles fell from stage to stage, all the outlets on the south and east were in turn abandoned, so that when the lake

FIG. 17. — LOOKING WEST, TOWARD SAND-PLAIN AT NEWTON LOWER FALLS, SHOWING EROSION-SLOPE ON NORTH SIDE OF RIVER.

finally completely disappeared from the basin of the Middle Charles, the new river had to take possession of the lowest outlet to the north, the pass midway between Medfield and Natick, through which it now flows.

North of Natick the new Charles reaches the valley of the old river, which, however, between Cochituate and Needham, has been blocked by the extensive sand-plains, forcing the new Sudbury to find an outlet to the north. The Charles, below South Natick, is forced to find a channel for itself along the southern border of the Needham plain, until it emerges, at Greendale, into another preglacial valley.

The circuitous course by way of Dedham, in place of the more direct one along Line Ditch, must have been caused by mere chance. Again, at Highlandville, the blocking of the preglacial valley by the sand-plain caused the river to deviate from its course, so that it now flows over solid rock at Newton Upper and Lower Falls, where it is still carving its gorges.

The characteristics of the drift deposits above the Upper Falls — irregular deposits, extending far out into the marsh — make it probable that there has been little postglacial erosion there. But at Newton Lower Falls the erosion slopes show that the sand-plain originally extended entirely across the valley, at a height of about 60 feet above the present river (Figure 17). When the stream first took this course, the plain acted as a barrier, which formed a lake between the Upper and the Lower Falls. In cutting down the outlet the present gorge was formed, and the river superimposed upon the bed-rock below, over which it now flows. During the development of the river several similar lakelets existed at different parts of its course.

Conclusion.

Having accomplished the first four of the five purposes stated in the introduction, it only remains for us to consider the fifth — to determine to what class of rivers the Charles belongs. Professor Davis has defined[1] several types, as follows: —

"An *original* river is one which first takes possession of a land area, or which replaces a completely extinguished river on a surface of rapid deformation.

"A river may be *simple*, if its drainage area is of practically one kind of structure and of one age. . . . It may be *composite*, when drainage areas of different structure are included in the basin of a single stream. . . .

"A *compound* river is one which is of different ages in its different parts. . . .

"A river is *complex* when it has entered on a second or later cycle of development."

We have already seen that our river taken as a whole is in a very youthful stage, having been formed by the filling with drift of several ancient valleys, formerly entirely distinct, and the development of their postglacial drainage into a single river system. Evidently,

[1] W. M. Davis: Rivers and Valleys of Penn., Nat. Geog. Mag., Vol. I, p. 218.

different portions must be placed in different classes, according to their respective histories. That portion between the source and South Milford is certainly *original*, but it is the only part of the river which *can* be called original. Certain portions taken separately are *simple*, but as a whole it is *composite;* for, as has been shown, such regions as those of the Middle Charles and the Boston Basin are entirely different in structure. Again, the river is *compound*, for its different parts differ greatly in age. As examples, may be noted the contrast between the topography of the Medway gorge and the valley of the Middle Charles, between the valley south of Needham and that north of the town, or between Hemlock Gorge and the basin to the southeast. All this shows that, throughout its course, the Charles is very *complex*. At several points it is a *superimposed* stream, as at Medway and again at Newton Upper and Lower Falls. Finally, as to whether it belongs with *consequent* or *antecedent* streams: — Powell has defined[1] the former as those whose courses are "consequent upon the constructional form of the land;" and the latter, as those which persist in their courses after a change by which others are destroyed. The Charles has entirely lost its *consequent* character. Parts of it, however, may be said to be *antecedent*, among these being the portion between Riverside and Boston, which occupies essentially its pre-glacial course.

From the foregoing general statements it is evident that the river as a whole cannot be placed in any one class, but that in studying it each portion must be classified according to its own characteristics. It is a stream occupying portions of several ancient valleys, which, having been obstructed by the drift of the ice age, have become connected by new channels, which now unite them into a single complex basin, in which flows the present peculiar and meandering river.[2]

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[1] J. W. Powell: Exploration of the Colorado River of the West, pp. 153, 163-166.

[2] The foregoing is the result of a thesis study done in the Geological Department of the Massachusetts Institute of Technology, and under the supervision of Professor W. O. Crosby.

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A LOGARITHMIC THREE-VARIABLE DIAGRAM FOR DATA OF THE FORM $a^m b^n c^p = k$.

ILLUSTRATED BY THE LAW FOR PERFECT GASES, $PV = RT$, WITH DIAGRAMS FOR VARIOUS GAS-ENGINE CYCLES.

BY HARRISON EVERETT ASHLEY.

GRAPHIC representation is the most successful way of preparing complex data for mental assimilation, and graphic processes displace many tedious calculations. The equilateral triangle, in which the sum of the perpendiculars from an included point to the three sides is a constant, has been used by Professors J. Willard Gibbs,[1] R. H. Thurston,[2] H. M. Howe,[3] C. R. A. Wright,[4] H. W. Bakhuis-Roozeboom,[5] W. D. Bancroft,[6] Hector R. Carveth,[7] F. A. H. Schreinemakers,[8] and others to show the variation of some physical property with variation in chemical composition of mixture of three chemical substances.

Professor Ernest A. Hersam[9] has shown very ingeniously how it may be used in the calculation of slags of three or four constituents. In the course of his discussion he says that a *right-angled triangle* may be used instead of the equilateral triangle, and "possesses some advantages in construction . . . . but the lack of symmetry and some other disadvantages make these departures generally less satisfactory for varied work."

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[1] Equilibrium of heterogeneous substances. Trans. Conn. Acad. (1876), vol. iii, p. 176.

[2] Tensile strength of copper-zinc-tin bronzes. Proc. A. A. A. S., 1877.

[3] Heat of solidification of lime-alumina-silica slags. Trans. Am. Inst. Min. Eng. (1898), xxviii, 346. Also discusses a triangular pyramid for four variables.

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[5] Zeit. phys. Chem. (1894), 15, 143.

[6] Jour. phys. Chem. (1897), 1, 403.

[7] Melting-points of KNO_3-$NaNO_3$-$LiNO_3$ mixtures. Jour. phys. Chem. (1898), 2, 209.

[8] Vapor pressure of ternary mixtures. Zeit. phys. Chem. (1901), xxxvi [3], 257.

[9] Trans. Am. Inst. Min. Eng. (1901), February.

Before seeing his paper, the writer of the present article had well-nigh completed a paper on "Slag Constitution, Studied by Means of the Tri-Axial Diagram with Rectangular Coördinates,"[1] in which the application was extended from the case $a + b + c = k$ to the more general case $ma + nb + pc = k$, where m, n, and p are any positive or negative, integral or decimal, real coefficients. The discussion was as follows:

"The tri-axial diagram is applicable only to the case of *three variables whose sum is a constant*, that is, to two independent variables. For example, if an alloy of tin, copper, and zinc be assumed to contain 15 per cent. of tin and 80 of copper, the percentage of zinc must be 5, the difference between 15 + 80 and 100. When the percentages of tin and copper have been fixed, that of zinc cannot be varied. But two independent variables can be shown by the common diagram with rectangular coördinates. A diagram showing only tin and copper percentages will serve to illustrate all the properties of the ternary

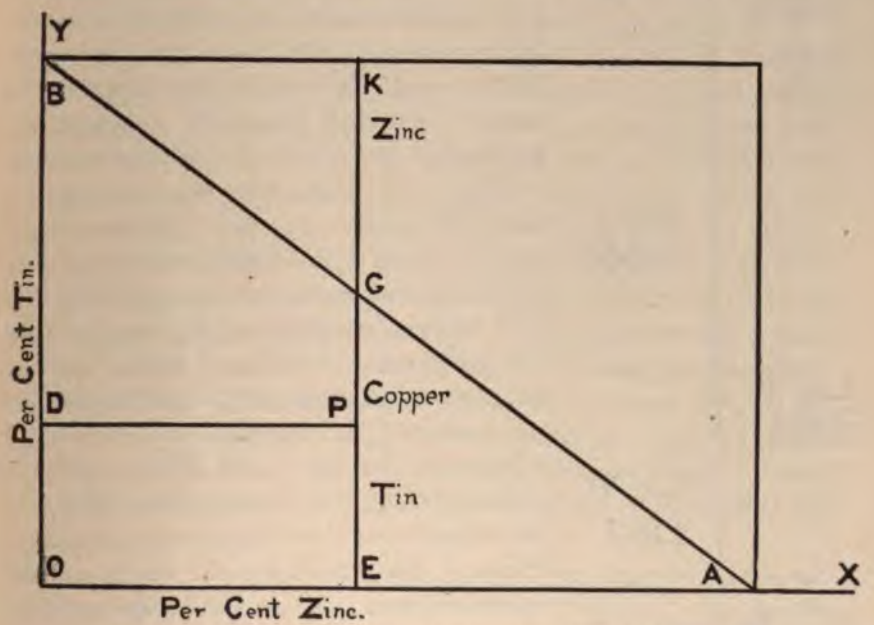

FIG. 1. — DERIVATION OF THE RECTANGULAR TRI-AXIAL DIAGRAM.

[1] Trans. Am. Inst. of Min. Engineers (1901), November.

bronze. Why use, then, the inconvenient oblique equilateral triangle diagram, when results can be plotted with comparative ease on ordinary cross-section paper, with rectangular coördinates, in an erect, right-angled triangle? Moreover, it is possible to read off from such a plot the third or dependent variable.

"In Figure 1, let any vertical line (as $EK = OB$) represent 100 per cent. of whatever mixture is under consideration, say tin-copper-zinc. Further, let the lower part (EP) of the line represent per cent. of tin, the upper part (GK) represent per cent. of zinc, and the middle part (PG), per cent. of copper. Then arrange the vertical lines along OX so that the abscissæ also shall represent the percentage of zinc, (*i. e.*, OE = percentage of zinc). We have now the per cent. of zinc represented by two separate means, one of which is superfluous; and we may accordingly dispense with the upper part of each vertical line, reducing the diagram from a rectangle to the triangle AOB. For any point P, the abscissa ($DP = OE$) represents per cent. of zinc; the ordinate ($PE = OD$) represents the per cent. of tin; and the distance along the vertical line (PG) to the hypothenuse AB represents per cent. of copper. The scales for the two quantities measured along the vertical lines are from the nature of the case the same, while the scale for the quantity measured by the abscissæ is the same as for the other two only in the case of the isosceles right-angled triangle. It is desirable to have all three variables plotted to the same scale.

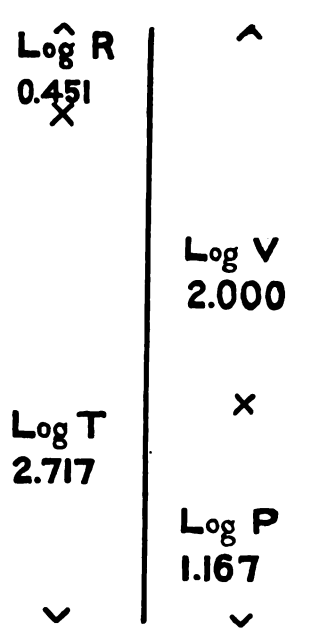

FIG. 2. — DERIVATION OF THE LOGARITHMIC THREE-VARIABLE DIAGRAM.

. . . . . .

"It is evident that the same principles may be applied to plotting data of the forms $a + b - c = k$ and $a - b - c = k$, or in general, of the form $ma + nb + pc = k$, where m, n, and p are any positive or negative, integral or decimal, real coefficients."

It soon occurred to the writer that this principle might be extended to data of the form $a^m b^n c^p = k_1$ by taking logarithms; thus

$m \log a + n \log b + p \log c = \log k_1 = k$, which is in the form already discussed. Since the logarithm of a variable factor may vary from $+\infty$ to $-\infty$, any logarithmic three-variable plot is only a limited portion of an infinite diagram.

The case of a perfect gas ($PV = RT$) will be used to illustrate the application of these principles. The following values, which are of suitable magnitude for ordinary gas engine practice, will be used to determine the constant R in the equation: Pressure (P) = 14.6967 pounds per square inch, volume (V) = 100 cubic inches, temperature (T) = 520°.66 Fahrenheit, absolute, corresponding to 60° F., common scale; from which $R = 2.822\ 7$. Taking logarithms, $\log P + \log V = \log R + \log T$, or $1.167\ 220_{(P)} + 2.000\ 000_{(V)} = 0.450\ 666_{(R)} + 2.716\ 554_{(T)}$. In Figure 2, the method of plotting is shown for a single vertical line. In Figure 3, the vertical lines are arranged with log temperatures as abscissæ. Since $\log R$ is a known constant, and $\log T$ is now shown by the abscissæ, the left hand part of Figure 2 becomes superfluous, and only P and V are given for the verticals hereafter. In Figure 4, instead of giving the actual logarithms, there are given the corresponding natural numbers. The diagram will present no inconvenience to anyone familiar with logarithmic plotting paper or with the slide rule, and no serious difficulty to anyone else, though the crowding of lines representing high values will at first seem peculiar. The use of natural numbers in the diagram obviates the necessity in computations of a double change, from numbers to logarithms and back again.

Since by the construction of the diagram the temperature is constant along a vertical line, *all isothermals* ($PV = P_1V_1$) *are parallel straight lines.*

Referring to Figure 2, it is seen that the algebraic length of the verticals varies proportionally to the logarithm of the temperature. Consequently on Figures 3 and 4, where abscissæ = log temperature, any basal $\log P$ line is a straight line, and *all lines of equal pressure* (*isopiestic*, $VT^{-1} = V_1T_1^{-1}$) *are parallel straight lines.*

In Figures 3 and 4, the line AB represents an adiabatic compression from the original volume of 100 cu. in. to a volume of 10 cu. in. The adiabatic is a straight line. This was experimentally proved by taking at random an intermediate volume and calculating its pressure and temperature, with the results given in the following table:

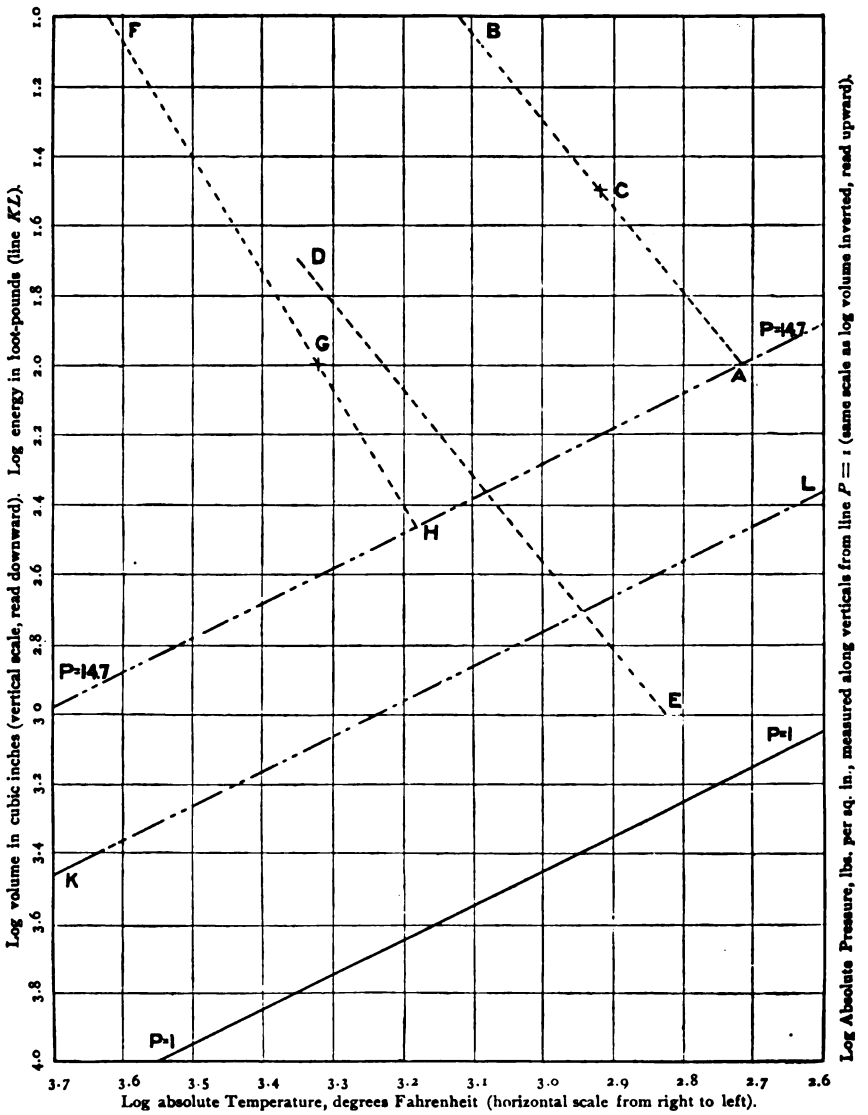

FIG. 3. — PROPERTIES OF A PERFECT GAS; LOGARITHMIC DIAGRAM, LOGARITHMS.

Based on 100 cu. in. at 60° F. and 14.7 lbs. absolute pressure. Adiabatic curves are any straight lines parallel to *AB*. Verticals are isothermals and lines of constant energy. Energy is given by intersections of line *KL* with the verticals read on left-hand scale. (See footnote, p. 281).

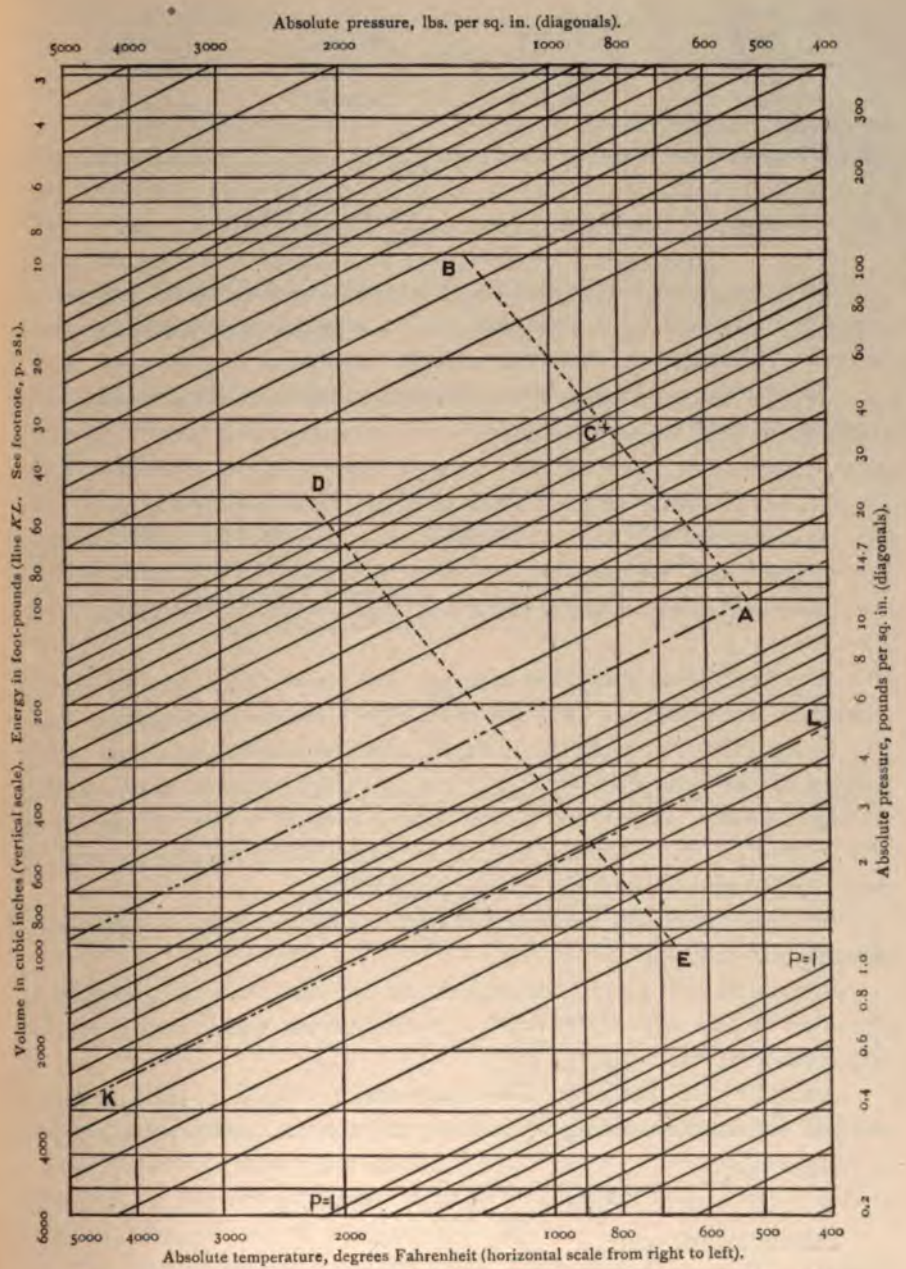
Absolute pressure, lbs. per sq. in. (diagonals).
5000 4000 3000 2000 1000 800 600 500 400
Volume in cubic inches (vertical scale). Energy in foot-pounds (line KL. See footnote, p. 284).
3 4 6 8 10 20 30 40 60 80 100 200 400 600 800 1000 2000 4000 6000
Absolute pressure, pounds per sq. in. (diagonals).
300 200 100 80 60 40 30 20 14.7 10 8 6 4 3 2 1.0 0.8 0.6 0.4 0.2
B
C
D
A
L
K
E
P=1
P=1
5000 4000 3000 2000 1000 800 600 500 400
Absolute temperature, degrees Fahrenheit (horizontal scale from right to left).

FIG. 4.— PROPERTIES OF A PERFECT GAS; LOGARITHMIC DIAGRAM, NATURAL NUMBERS.

Based on 100 cu. in. at 60° F. and 14.7 lbs. absolute pressure (point *A*).
Adiabatic curves, etc., as in Fig. 3.

Point.	A.	C.	B.
log P	1.167 220	1.869 720	2.572 220
log V	2.000 000	1.500 000	1.000 000
log T	2.716 554	2.919 054	3.121 554

$$\text{Tangent of line connecting } A \text{ and } C = \frac{1.500\,000 - 2.000\,000}{2.919\,054 - 2.716\,554} = -2.469\,14.$$

$$\text{Tangent of line connecting } C \text{ and } B = \frac{1.000\,000 - 1.500\,000}{3.121\,554 - 2.919\,054} = -2.469\,14.$$

Now the point C was chosen at random, and the line is shown to have the same direction both sides of it; consequently it has the same direction throughout, and is a straight line.

To find the relation between different adiabatics, the following was chosen at random and computed:

Point.	D.	E.
log P	2.103 879	0.275 932
log V	1.698 970	3 000 000
log T	3 352 183	2.825 266

$$\text{Tangent of line connecting } D \text{ and } E = \frac{1\,698\,970 - 3\,000\,000}{3.352\,183 - 2\,825\,266} = -2.469\,13,$$

i. e., the line DE is parallel to the line AB. But DE is any adiabatic; therefore, *all adiabatics* ($PV^{1.405} = P_1V_1^{1.405}$) *are parallel straight lines.*

In exactly the same manner, it may be shown that any other curves of the form $PV^n = P_1V_1^n$ for any given value of n are parallel straight lines. In Figure 3, the line FGH is a line of the form $PV^{1.3} = P_1V_1^{1.3}$. Another line of the same form passing through A was computed, and had the same tangent.

Accordingly *all the common gas engine diagrams may be represented by straight lines.*

A construction giving the inclination for any required exponential equation of the form $PV^n = P_1V_1^n$ may be derived from the following considerations:

According to Peabody, *Thermodynamics* (1898), p. 69, the exponential equation involving volume (v) and absolute temperature (T) is

$$Tv^{n-1} = T_1v_1^{n-1}, \text{ or } \left(\frac{v}{v_1}\right)^{n-1} = \frac{T_1}{T}.$$

Taking logarithms:

$$n - 1\ (\log v - \log v_1) = \log T_1 - \log T, \text{ or}$$

$$n - 1 = \frac{\log T_1 - \log T}{\log v - \log v_1}.$$

If we consider compressions from $v = 100$ to $v_1 = 10$, the denominator of the above fraction becomes unity, and the equation:

$$n - 1 = \log T_1 - \log T.$$

To apply this construction to Figure 3, let us suppose the inclination is desired of curves for which $n = 1.43$. For point A (volume 100) the log temperature (T) is 2.716 554 2. Add 0.43, and we get log temperature (T_1) 3.146 554 2, corresponding to volume 10. We thus have two points giving the required inclination.

Since entropy is constant along an adiabatic, a scale of entropy may be added to the diagram by drawing a proper series of adiabatics (not done in this paper).

Isothermals are considered also lines of constant energy, and energy considered proportional to the temperature. It is, however, undesirable to confuse the diagram by the addition of a separate scale of energy, and the same end is accomplished by drawing the line KL intersecting the verticals in such positions that the intersections read off on the scale of volumes give *a scale of energy*. Referring to Peabody, *Thermodynamics* (1898), p. 68, the intrinsic energy of a perfect gas,

$$E = \frac{p v}{\kappa - 1} \text{ ft. lbs.},$$

where p = lbs. per sq. ft., and v = cu. ft. This may be altered as follows:

$$E = \frac{p \times 144 \times v}{(1.405 - 1)\ 1728},$$

where p = lbs. per sq. in., and v = cu. in. Then, by the gas law, $pv = RT$,

$$E = \frac{R\,T}{.405 \times 12} = \frac{2.822\ 7}{.405 \times 12}\ T,$$

where for deriving R, $p = 14.7$ lbs. per sq. in., $v = 100$ cu. in., and T = absolute temperature in Fahrenheit degrees. Simplifying, $E = 0.580\ 80\ T$ for that quantity of gas that measures 100 cu. in. at 60° F. and 14.7 lbs. per sq. in. absolute pressure.

While the diagrams so far given apply only to a certain definite amount of gas which is acted upon, acts, and is completely expelled at the end of the cycle, it is the case in practice that a variable clearance

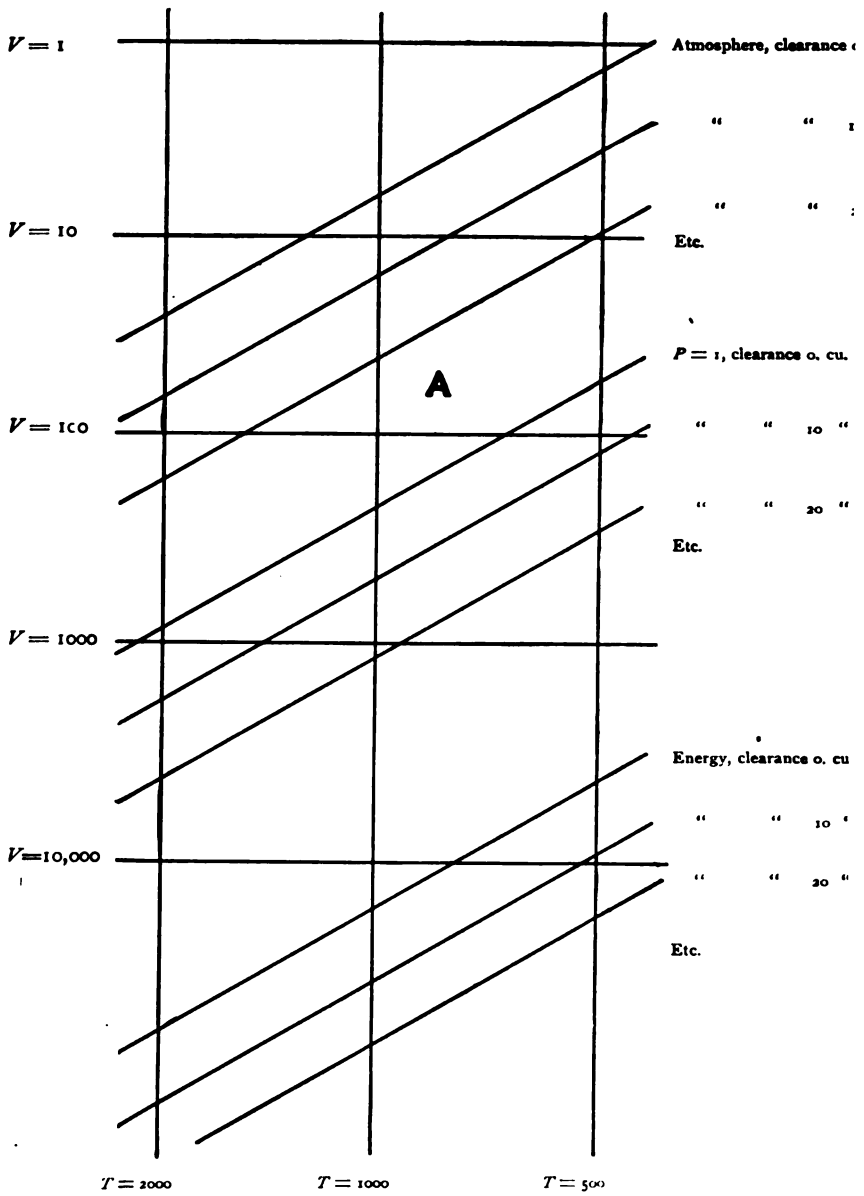

FIG. 5. — DIAGRAM ALLOWING FOR VARIATION IN CLEARANCE.

occupied by an inert gas must also be considered. This may be provided for by a modification of Figure 3 or 4.

Referring to Figure 2, suppose we take an initial volume of 110 cu. in. corresponding to 100 cu. in. piston displacement and 10 cu. in. clearance, the effect will be to increase V and R. On Figures 3 and 4 this might be shown by another $P = 1$ line still lower down on the diagram. The volume and temperature lines would be unchanged, but all the pressure and the energy lines would have to come down, the

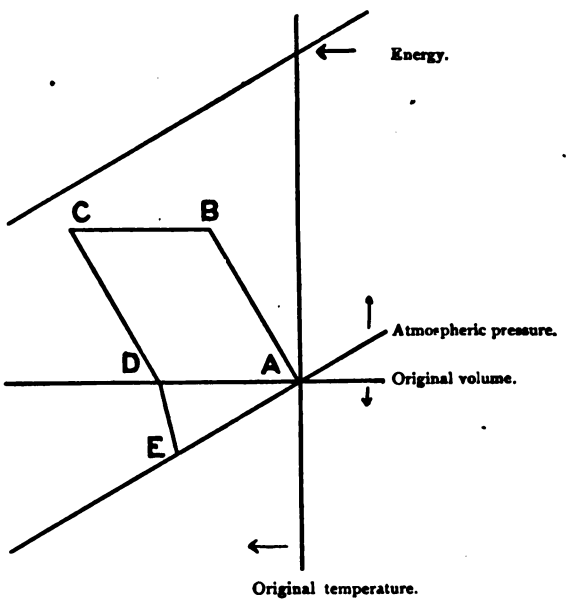

FIG. 6. — DIAGRAM FOR ORDINARY GAS-ENGINE CYCLE.

former an amount equal to the difference between the two $P = 1$ lines. As indicated roughly in Figure 5, a series of $P = 1$, atmospheric, other pressure, and energy lines might be drawn corresponding to convenient clearances. In using such a diagram to find the properties of any point A with a clearance of, say, 10 cu. in., read off volume and temperature as usual, energy from the intersection of A's ordinate with the line *energy, clearance 10 cu. in.*, pressure by taking with dividers the distance along A's ordinate from A to the line $P = 1$, *clearance 10 cu. in.*, then putting one point of the dividers on the line $V = 1$ whereupon the other point will reach down to some volume, say, $V = 9$; then P is 9 for the point A; for P and V are measured to the same logarithmic scale.

Diagrams will now be shown for several types of gas engines, giving the changes of a fixed quantity of gas. The arrows show the directions in which the variables increase in magnitude.

The ordinary cycle, Figure 6: *A*, drawing in of charge, no change of properties. *AB*, moderate compression; temperature, energy, and pressure increase; entropy (measured by distance between adiabatics) varies little or none; volume diminishes. *BC*, ignition; volume con-

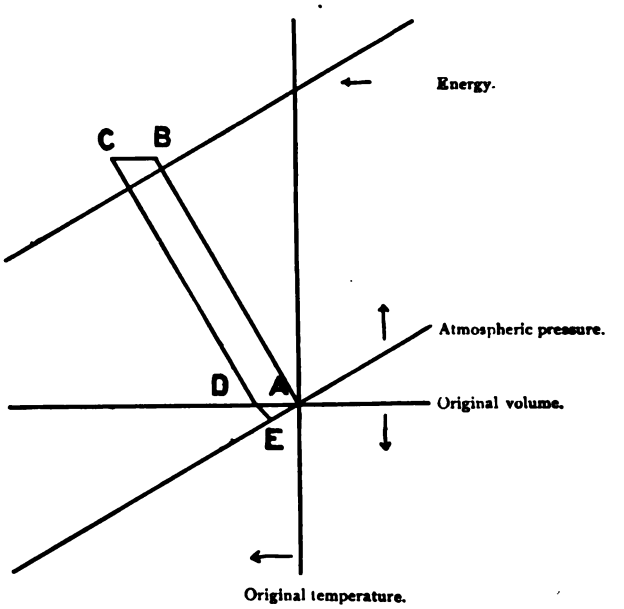

FIG. 7. — THE DIESEL MOTOR DIAGRAM.

stant, pressure, temperature, energy, and entropy increase. *CD*, expansion; entropy varies little or none; volume increases; pressure, energy, and temperature fall. *DE*, adiabatic release into the atmosphere; volume becomes greater than that of the cylinder; *DE* makes an angle with *CD* if *CD* is not an adiabatic; pressure falls to atmospheric; entropy remains constant; energy and temperature fall. *E* removal of waste gases; no change of properties. The energy developed by combustion is the difference between the abscissæ for the vertical lines through *B* and *C*; the energy rejected, minus the original energy of the gas is the difference between *D* and *A*.[1] This is

[1] Energy and temperature, which are considered proportional to each other, are constant along the ordinates. Energy, measured by abscissæ, would be most easily represented by a horizontal scale, but I wished to reserve that means to show temperatures, so drew the line *KL* intersecting volume scale and *undrawn* energy scale *of the same numerical value.*

probably always less than the difference between B and C, since the higher values are closer together in the logarithmic diagram.

It is evident that one aim of gas-engine design should be to get D (release) and A (charge) as close together as possible, and so reduce the energy loss. This is done in the Diesel motor (Figure 7)[1] by extreme compression, the energy imparted by ignition (BC) is not diminished, but owing to its logarithmic position the diagram is narrowed, and D approaches A. With an infinite compression AB and CD would coincide, and all the energy of compression and ignition would be given up in the expansion CD.[2]

Another device is expansion to atmospheric pressure (Figure 8). The difference in energy between F and D is saved; D and E coincide; the energy between E and A is still lost. There is not, as is the case with the Diesel motor, any possibility of complete utilization of the energies of compression and ignition. As the compression is increased with this type, the diagram is narrowed and the gain due to the increased expansion falls off (*i. e.*, the energy abscissæ of F and D approach equality).

[1] The Diesel motor cycle cannot strictly be represented by my diagram; since, after compression the amount of matter in the cylinder is increased by the injection of oil, and my diagram requires a fixed quantity of matter. Figure 7 shows correctly how the high compression of the Diesel motor produces economic results. Compare the *discussion* of a paper by Eddy, "A New Graphical Method of Constructing the Entropy Temperature Diagram of a Gas or Oil Engine from its Indicator Card." (*Trans Am. Soc. Mech. Eng.*, 1900, pp. 275–291.)

[2] To give an illustration of the gain in efficiency from using high compression, the following case has been worked out from a smaller plot than the original of Figure 3, using a 10-inch slide-rule to convert numbers to and from logarithms. Suppose 100 cu. in. gas to be compressed adiabatically to 100, 70, 20, 10, or 0 cu. in., and then to receive an increase in temperature (energy is considered proportional to temperature) of 1,200° F. (a very small value) in each case, and expand adiabatically to original volume. The results would be as tabulated below, and these may be verified in Figure 4.

Remarks.	Volume at compression.	Temperature at Compression.	Same + 1,200° F. = Temperature at Ignition.	Temperature at original volume after expansion.	Difference between original temperature and temperature after expansion.
No compression. No expansion.	100 cu. in.	521	1,721	1,721	1,200
	70	602	1,802	1,561	1,040
	20	1,000	2,200	1,146	625
	10	1,326	2,526	989	468
All energy of compression restored. All energy of combustion utilized.	0	521 + ∞	521 + ∞ + 1,200	521 + ∞ + 1,200 − ∞ − 1,200 = 521	0

An expansion to original temperature (*G*, Figure 8) would indeed utilize all the energies of compression and ignition, but a vacuum-producing device, like the condenser of a steam engine, would hardly give the good results obtained in steam engine practice.

The difference of intrinsic energy of two points on a compression or expansion curve is not a measure of the external mechanical work done by the gas in an engine cylinder in passing from one of the con-

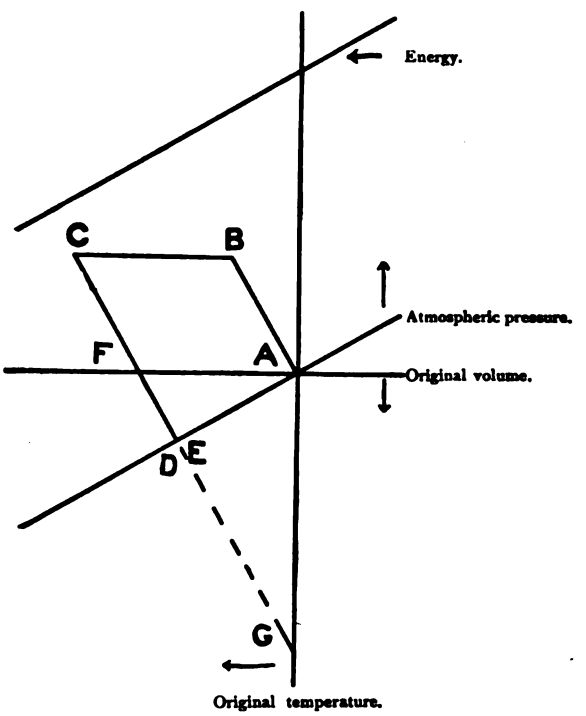

FIG. 8. — DIAGRAM SHOWING COMPLETE EXPANSION.

ditions to the other; for the gas may transform or fail to transform into mechanical work energy received from or lost to the cylinder walls, etc.

A plot about 16 inches square containing the upper part of Figure 4, on a scale of 5 inches = change of 1.000 in log volume, will give with fair precision three significant figures, sufficient for many ordinary purposes. A scale of 10 inches = change of 1.000 in log volume is more easily read and preferable. Ordinary logarithmic plotting

paper of the size 1 — 100 may be used, but I think it better to have the temperatures, as in Figures 3 and 4, at twice the logarithmic scale of the volumes.

Given this plot (Figure 4) and a little careful instruction, a man knowing nothing of algebra, logarithms, calculus, or thermodynamic equations ought, in the opinion of the writer, to be able to figure gas-engine design intelligently. The preceding discussion is not, however, very well adapted to his enlightenment. He needs directions, not derivation.

While this paper has discussed a *logarithmic* three-variable diagram, other functions may be plotted whenever the expressions can be put in the form of three simple quantities whose algebraic sum is a constant, *e.g.*, $\tan a + \log \tan b + pc = k$, etc.

The method of plotting is much better adapted to exhibiting, calculating, or verifying data following known laws, than to deriving formulæ from experimental data. As a method of deriving formulæ, the best thing that suggests itself to me is a soft board and a box of pins, each bearing a label. On each label is put the data corresponding to some one condition experimentally determined. The pins are distributed upon the board in such manner, if possible, that each variable varies continuously. If this succeeds and suggests a formula, the formula may be tested by a plot. The size of the triangle between the lines representing the experimental determination of some one condition is an indication of the variation of the data from the assumed law, and may or may not suggest modification of the same.

Summary.

The tri-axial diagram with rectangular coördinates may be used to plot data of the forms $ma + nb + pc = k$, and $a^m b^n c^p = k$ where m, n, and p are any positive or negative, integral or decimal, real numbers.

For perfect gases, one plot will give with no confusion, pressure, volume, temperature, entropy, and intrinsic energy.

All the lines used in ordinary gas-engine diagrams are straight lines on such a diagram.

A diagram may be made that will allow for the effect of varying clearance.

The conditions for economy from using compression, expansion to atmospheric pressure, and expansion to original temperature are sharply defined, and their mutual relations made apparent.

A man with no knowledge of algebra, logarithms, calculus, or thermodynamic equations can, the writer thinks, by means of the diagram, design gas engines intelligently.

The method may be extended to other than logarithmic functions.

The method can probably be used in deducing formulæ for the results of experimental determinations.

METHOD OF CALIBRATING TURBIDIMETERS.

By GEORGE C. WHIPPLE and DANIEL D. JACKSON.

The Section of Bacteriology and Chemistry of the American Public Health Association at its annual convention, held at Buffalo in September, 1901, adopted the report of progress of the Committee on Standard Methods of Water Analysis. This report included the recognition of the Silica Method as an official standard for estimating the turbidity of water. It does not imply that direct readings upon the silica scale shall be made always, but that, whatever method is used for the measurement of turbidity, the results shall be reduced to this scale and expressed in terms of silica in parts per million. Observations which have been made with the diaphanometer, or turbidimeter, and expressed according to some form of reciprocal scale ought hereafter, if the action of the Section is followed, to be expressed according to the silica standard. Hence, for convenience these instruments should be graduated in parts per million of silica. As the authors have been asked several times to explain the method of calibrating a turbidimeter, it has been thought best to put this explanation into permanent form in order that it may be available for future reference.

The use of the diaphanometer has been described by Hornung,[1] Parmelee and Ellms[2] and by the authors.[3]

The essential parts of the instrument are shown in Figure 1. They consist of a vertical tube for holding the sample, which has opaque sides and bottom, save for an opening at the bottom in the form of a cross, through which light may enter; a standard source of light,

[1] George Hornung: Diaphanometer for Measuring the Transparency of Water. A paper read before the Engineers' Club of Cincinnati, March 19, 1896.

[2] Parmelee and Ellms: On Rapid Methods for the Estimation of the Weight of Suspended Matter in Turbid Waters. Technology Quarterly, Vol. XII, No. 2, June, 1899.

[3] The authors: A Comparative Study of the Methods Used for the Measurement of the Turbidity of Water. Technology Quarterly, Vol. XIII, No. 3, September, 1900.

generally a Wellsbach burner; a condenser; and a reflector for transmitting the light upwards through the tube. The reading is made by pouring the sample into the tube until the cross of light disappears

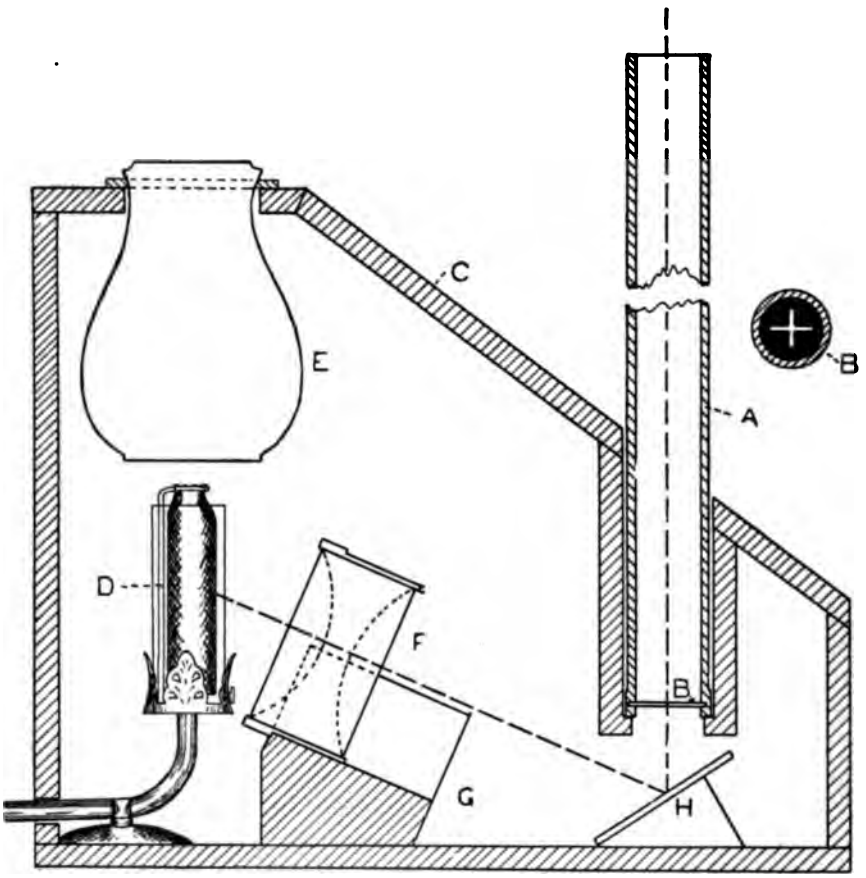

FIG. 1.—CROSS SECTION OF DIAPHANOMETER AS USED BY GEORGE W. FULLER AT CINCINNATI.

A, Tube for holding sample; *B*, Cross of light at bottom of tube; *C*, Case; *D*, Wellsbach burner; *E*, Chimney; *F*, Condenser; *G*, Block supporting condenser; *H*, Reflector.

from view. The depth of liquid in the tube may be obtained by dividing the amount poured in, expressed in cubic centimeters, by the cross section of the tube in square centimeters.

The calibration consists in determining this depth for waters made turbid by the addition of different known amounts of standard

silica, and in compiling from these observations a scale from which future observations of turbidity may be obtained. Inasmuch as local conditions, especially as regards the intensity of the light, are subject to variation, it is necessary to calibrate each instrument under the conditions in which it is to be used. For the method of preparing the silica standard the reader is referred to a previous paper of the authors published in this journal.[1] To calibrate a diaphanometer, or turbidimeter, proceed as follows:

Start with a silica standard of 1000. Pour this into the tube, and at the point where the cross of light becomes obscured measure the amount that has been poured in, or measure the depth of the liquid in the tube. For convenience of description we may consider that the depth may be read directly, which is the case when a removable glass tube inside an opaque tube is used. Repeat the operation several times, each time thoroughly shaking the standard, until the depth has been determined with exactness. Dilute the standard with clear water until it contains but 900 parts of silica per million, and determine the depth at which the cross of light disappears as before. Continue this process, using successive dilutions, until the observations have covered the range of the instrument. The results of these observations may be marked on the tube, or a table may be constructed, giving the turbidity in parts per million of silica corresponding to different depths. Observations which lie between the calibrated points must be obtained by interpolation. The larger the number of observations made, the more accurate will be the scale.

Instead of graduating the instrument directly, however, greater accuracy may be obtained by plotting the observations and drawing a curve which will represent the results, thus avoiding errors of individual observations. Such a curve is shown in Figure 2.[2] The abscissas represent the turbidity of the standard in parts per million of silica; the ordinates represent the depth of liquid in the tube. A calibration table may be made from this curve by reading the turbidities which correspond to various depths, but it is advisable to determine the formula of the curve and calculate these values.

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[1] TECHNOLOGY QUARTERLY, Vol. XII, No. 4, December, 1899.

[2] It is preferable to use logarythmic cross-section paper for this purpose.

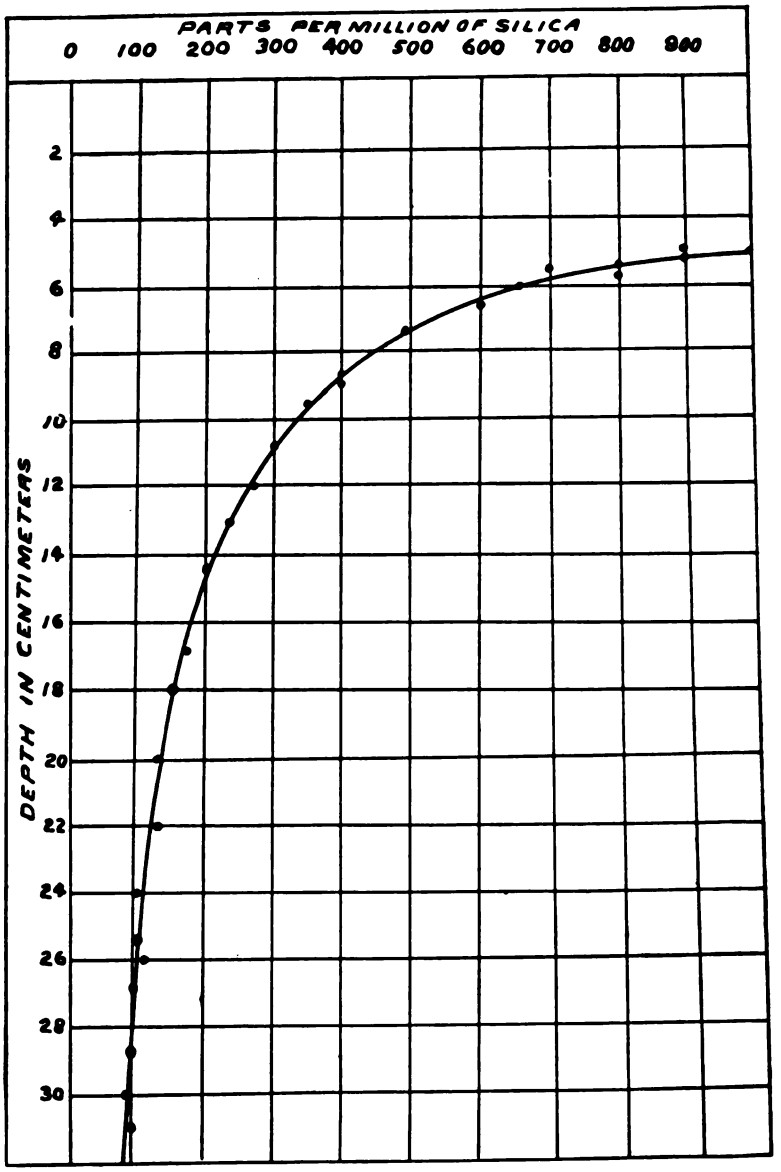

FIG. 2.—EXAMPLE OF THE CALIBRATION OF A TURBIDIMETER, SHOWING THE DEPTH OF LIQUID IN THE TUBE FOR VARIOUS DEGREES OF TURBIDITY.

Experience has shown that the curve may be represented by an equation which has the form of

$$x = \frac{c}{y + a}$$

where x = the turbidity in parts per million of silica,
y = the depth of liquid in the tube, and where
c and a are constants.

The constants are determined as follows: From the plot read the values of x which correspond to certain integral values of y. Thus from the curve shown in Figure 2, we find that

If $y = 5$, $x = 1000$.
If $y = 6$, $x = 650$.
If y $= 7$, $x = 520$, etc.

Assume for c some value of x, as, for example, 1000; and substitute this and various values of x and y in the general equation, obtaining a series of equations as shown below. From each of these equations calculate the value of a. Thus:—

$$1000 = \frac{1000}{5 + a}, \quad \text{from which } a = -4.00$$

$$650 = \frac{1000}{6 + a}, \qquad a = -4.46$$

$$450 = \frac{1000}{7 + a}, \qquad a = -5.78$$

$$330 = \frac{1000}{10 + a}, \qquad a = -6.99$$

$$190 = \frac{1000}{15 + a}, \qquad a = -9.74$$

$$130 = \frac{1000}{20 + a}, \qquad a = -12.31$$

Next find the value of a in terms of y by making a second plot, as shown in Figure 3. In this case values of a are plotted as abscissas and values of y as ordinates. These values will ordinarily fall in a straight line over the portion of the scale where the observations can be accurately made. From the illustration[1] given it is evident that

$$a = -\frac{y + 1.8}{1.7}$$

[1] When $a = 10$, $y = 15.5$. As the line cuts the axis of a 1.8 below the axis of y, the slope of the line is shown by the ratio 10 : 15.5 + 1.8, or 10 : 17.3, or approximately 1 : 1.7; hence, $a = -\frac{y + 1.8}{1.7}$.

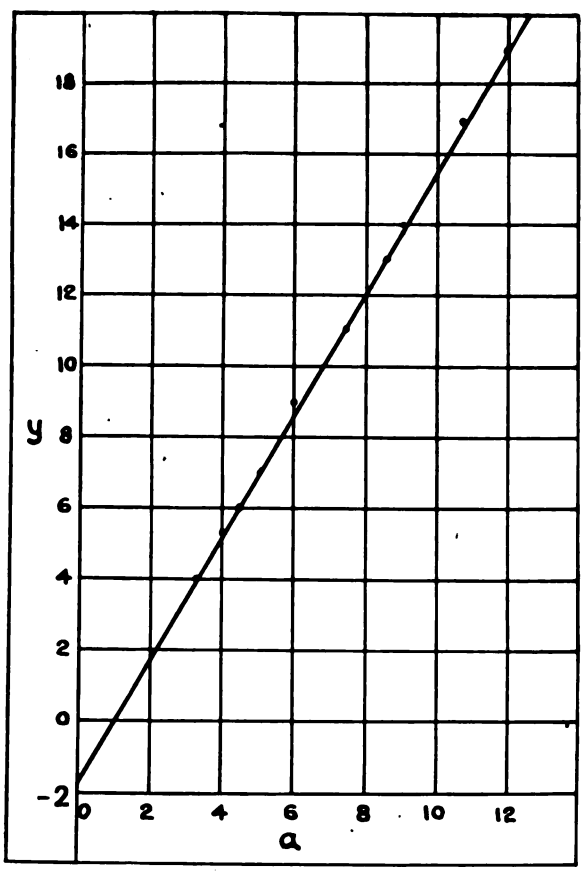

FIG. 3. — PLOT TO FIND THE VALUE OF *a* IN TERMS OF *y*.

If this value is substituted in the general equation with c assumed as 1000, we have $x = \frac{1000}{y - \frac{y + 1.8}{1.7}}$, or $x = \frac{2430}{y - 2.6}$ as the equation of the curve.

From this equation it is possible to compute a table giving the turbidity in terms of the silica standard which corresponds to any depth of liquid in the tube when the cross of light disappears.

A new and more convenient form of turbidimeter is described by one of the authors in the *Journal of the American Chemical Society*, November, 1901.[1] This instrument, which is shown in Figure 4, may be used for the determination of the turbidity in water where the turbidity is over 100 on the silica scale. Turbidities of less than 100 are compared directly with the standards in tubes or bottles.

The advantage of this instrument is that standard conditions are used so that the formula for reading is always the same. Consequently a permanent calibration has been made on the instrument, and the turbidity may be read directly in parts per million of silica from the graduation on the tube.

The instrument consists of a tube 25 cm. long and 2.5 cm. in inside diameter, graduated from the bottom upwards in centimeters and millimeters in depth. The tube is also graduated in parts per million of silica according to the formula

$$x = \frac{2485}{y + .75}$$

where x = the parts per million of silica and y = the depth in centimeters at which the image of light disappears.

The following table will facilitate the permanent graduation of the instrument.

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[1] Jackson, D. D.: The Photometric Determination of Sulphates.

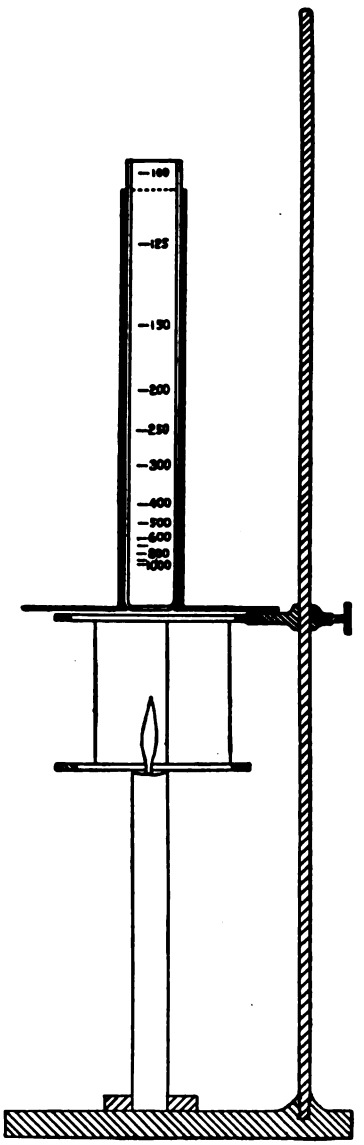

FIG. 4. — SECTION OF THE IMPROVED TURBIDIMETER.

TABLE FOR GRADUATING THE TURBIDIMETER IN PARTS PER MILLION OF SILICA.

Parts per Million of Silica.	Depth in cm.	Parts per Million of Silica.	Depth in cm.
1000	2.3	290	7.5
900	2.6	280	7.8
800	2.9	270	8.1
700	3 2	260	8.4
650	3.5	250	8.7
600	3.8	240	9.1
550	4.1	230	9.5
500	4.5	220	9.9
450	4.9	210	10 3
400	5.5	200	10.9
390	5.6	190	11.4
380	5.8	180	12.0
370	5.9	170	12.7
360	6.1	160	13.5
350	6.3	150	14.4
340	6.4	140	15.4
330	6.6	130	16 6
320	6.8	120	18.0
310	7.0	110	19.6
300	7.3	100	21.5

The glass tube can be slipped into a holder which envelops the sides and is open at the bottom, except for a narrow rim which serves to hold it in place. The bottom of the tube is on a level with the bottom of the holder. A flange 12 cm. in diameter shuts out the stray light of the candle from the eyes. Readings are made in the dark room. A standard candle is used, the top of which is just 3 inches (7.6 cm.) below the bottom of the glass tube when in place for reading.

The instrument is held by an adjustable iron ring. A second ring suspended 3 inches below the first marks the point at which

the top of the candle should come. The candle is lighted and the liquid to be tested for turbidity is then poured into the glass tube until the image of the light just disappears. The reading in parts per million expressed in the silica standard is then taken directly from the glass tube. The bottom of the meniscus should always be taken for the reading.

The simplicity of this instrument and the rapidity with which readings may be made should recommend it above other types of turbidimeters.

Mt. Prospect Laboratory,
Brooklyn, N. Y.

CONTRIBUTIONS FROM THE LABORATORY OF SANITARY CHEMISTRY.

III.

A PORTABLE OUTFIT FOR WATER ANALYSIS.

BY A. G. WOODMAN.

THERE is a constantly increasing demand in water analysis, as in other branches of sanitary science, for more field work. The laboratory for water analysis, though equipped with the best apparatus and in charge of the most skillful analysts, is hampered by restrictions of time and distance. It is not always possible for the mountain to come to Mahomet, and in these cases Mahomet must go to the mountain. There is a large field of usefulness for the laboratory which can be brought directly to the well or river. There is, moreover, oftentimes a considerable saving of expense in making a preliminary survey with simple apparatus before calling into requisition all the paraphernalia needed for final work.

In making preliminary examinations of most likely sources for a town or city supply; in testing the available water supply for a camp, whether of soldiers or pleasure seekers; in the hands of the sanitary engineer, seeking, it may be, to explore and develop our new island possessions; in cases like these the value of a simple, portable outfit will be apparent. The development of the mining interests of the West would have been sadly hampered if the assay laboratory had not been supplemented by the prospector's "kit."

The water analysis kit which is here described has been arranged in the hope that it may prove of use in the service of the prospector for pure water. Cabinets of apparatus and reagents for water analysis are on the market, but what is especially desired is a case which can be made at only slight expense and fitted up from material to be found in every water analysis laboratory. It is not expected that the contents and the arrangement will in every instance be exactly similar

to those of the outfit described, for these will undoubtedly be varied to suit individual preferences as to tests and methods; these are to be taken simply as suggestions in this line.

A general view of the interior of the case, open, and filled with the reagents and apparatus, may be had from the accompanying illustration, reproduced from a photograph. It is made of light wood, $\frac{1}{4}$ inch thick, of the following outside dimensions: 15 inches long, $13\frac{1}{2}$ inches high, $4\frac{1}{4}$ inches deep. The top is hinged so as to turn back, and the front swings outward. The reagent bottles, which are of two sizes, containing 75 c.c. and 100 c.c. respectively, are carried

INTERIOR OF CASE, SHOWING ARRANGEMENT.

on the bottom and on a shelf above. The upmost shelf is divided into compartments for the more convenient storage of small pieces of apparatus. Horizontal wooden strips on the inside of the door serve as a rack for test tubes, and when the door is closed press against the reagent bottles and hold them firmly in place. Nessler tubes are carried horizontally in loops of elastic "webbing" on the inside of the door, and pipettes in the same way on the under side of the top. It is hardly necessary to give the exact dimensions for the interior fittings, since these will vary with the size of the bottles and apparatus. The case is provided with a handle at the top, and is of a convenient shape to carry in the hand. Complete, it weighs about ten pounds. A small wire ring suitable for holding a crucible

or small dish is attached at one side where it can be readily swung out for use, and a clamp for holding a pipette when used as a burette is fastened to the door. Other simple and convenient bits of apparatus will readily suggest themselves.

The following pieces of apparatus are provided:

1 — 10 c.c. pipette graduated in tenths.
1 — 5 " " "
2 — 2 " " hundredths.
25 c.c. calibrated flask.
2½-inch porcelain evaporating dish.
2 — No. 7 porcelain crucibles.
Small drinking cup.
Candle.
2 — Nessler tubes marked at 50 c.c.
6 — Test tubes.
Test tube brush.
Short pieces glass tubing.
Stirring rod.
Burette tip for converting pipette into a burette.
100 c.c. glass-stoppered bottle.

The reagents, which are carried in glass-stoppered bottles, are as follows:

100 c.c. Nessler solution.
" Potassium hydroxide (20 per cent. solution).
" Sulphuric acid (sp. gr. 1.84).
" Acidified silver nitrate.
" Soap solution.
" Potassium permanganate $\left(\text{App. } \frac{N}{100} \text{ solution}\right)$.
75 c.c. Sulphanilic acid.
" Naphtylamine acetate.
" Phenol disulphonic acid.
" Diphenylamine (solid).
" Potassium permanganate (crystals).
" Potassium sulphocyanate (5 grams per liter).
" Hydrochloric acid (sp. gr. 1.12).
" Barium chloride (10 per cent solution).

The preparation of some of the less common reagents in this list will be briefly described.

Nessler Solution. — Dissolve 61.75 grams KI in 250 c.c. distilled water and add a cold saturated solution of $HgCl_2$, which has been made by boiling with an excess of the salt and allowing it to crystallize out. Add the $HgCl_2$ cautiously until a slight permanent red precipitate (HgI_2) appears. Dissolve this precipitate by the addition of 0.75 gram powdered KI. Add 150 grams KOH, dissolved in

250 c.c. of water, make up to a liter, and allow it to settle twenty-four hours. Decant for use. This solution should give a maximum color with ammonia within five minutes.

Sulphanilic Acid.— Dissolve 0.5 gram of sulphanilic acid in 150 c.c. of acetic acid, sp. gr. 1.04.

Naphtylamine Acetate.— Boil 0.1 gram of *a*-naphtylamine in 20 c.c. of water; filter through a plug of washed absorbent cotton, and add 180 c.c. of acetic acid, sp. gr. 1.04.

Phenol Disulphonic Acid.—Heat together 3 grams synthetic phenol and 37 grams pure, concentrated sulphuric acid in a boiling water-bath for six hours.

Acidified Silver Nitrate.— A 5 per cent. solution of silver nitrate made strongly acid with nitric acid.

Soap Solution.— Dissolve 100 grams of the best white, dry castile soap in a liter of 80 per cent. alcohol. Of this strong solution dilute 75 to 100 c.c. to a liter with 70 per cent. alcohol. Add 70 per cent. alcohol until 14.25 c.c. of the resulting solution gives a lather persisting for five minutes with 50 c.c. of a standard calcium chloride solution (1 c.c. = 0.000200 gram $CaCO_3$).

The tests which can be applied to a water by means of this outfit and the manner of making them are as follows:

(1) *Color.*— Fill a Nessler tube to the mark with the water and observe the depth of color, looking lengthwise of the tube against a piece of white paper. Record as very slight, slightly yellow, light straw, dark brown, etc.

(2) *Free Ammonia.*— Fill a Nessler tube to the mark with the water, drop in about a cubic centimeter of the Nessler solution and after five minutes note the color and record as above. If the water itself has much color, this will interfere and the test should then be made comparative, using two Nessler tubes and Nesslerizing only one.

(3) *Nitrites.*— Fill a test tube half full of the water and with a glass tube add 2 c.c. each of sulphanilic acid and naphtylamine acetate. Observe the color at the end of five minutes.

(4) *Nitrates.*— (*a*) Measure 1 c.c. of the water into a porcelain crucible. Evaporate quickly just to dryness over a candle flame. Add 2 drops of phenol disulphonic acid and then 2 to 3 c.c. of potassium hydroxide solution. The yellow color can be seen when the nitrate amounts to .100 part per million or more. If the yellow color

is very deep, a better idea of the amount of nitrate present may be had from test (*b*).

(*b*) Place in the porcelain dish a bit of diphenylamine the size of a pinhead. Add 10 drops of strong sulphuric acid and mix thoroughly with a glass rod. Let *one* drop of the water fall directly on the acid and note if any blue color appears within one to two minutes. Do not mix after adding the water. The test carried out in this way will show the presence of 2.000 parts per million, or more, of nitrates.

(5) *Chlorine.*— Use 25 c.c. of the water in a test tube and about 1 c.c. of acidified silver nitrate. No appreciable milkiness means less than 5 parts per million; distinct milkiness, 10 parts; clotted precipitate, 40 parts; heavy precipitate, settling readily to the bottom, 100 parts or more.

(6) *Hardness.*— Carry out the test in the usual manner, using 25 c.c. of the water in a 100 c.c. bottle and titrating with the soap solution from a pipette. Values taken from the table which is appended will be fairly close and serve for comparison.

PARTS OF $CaCO_3$ IN 1,000,000 FOR EACH TENTH OF A CUBIC CENTIMETER OF SOAP SOLUTION USED.

C.C.	0.0 c.c.	0.1 c.c.	0.2 c.c.	0.3 c.c.	0.4 c.c.	0.5 c.c.	0.6 c.c.	0.7 c.c.	0.8 c.c.	0.9 c.c.
0.0				0.0	1.6	4.8	7.9	11.1	14.3	16.9
1.0	19.5	22.1	24.7	27.3	29.9	32.5	35.1	37.7	40.3	42.9
2.0	45.7	48.6	51.4	54.3	57.1	60.0	62.9	65.7	68.6	71 4
3.0	74.3	77.1	80.0	82.9	85.7	88.6	91.4	94.3	97.1	100.0
4.0	103.0	106.0	109.0	112.0	115.0	118.0	121.1	124.1	127.1	130.1
5.0	133.1	136.1	139.1	142.1	145.2	148.4	151.6	154 8	157.9	161.1
6.0	164.3	167.5	170.6	173.8	177.0	180.2	183.3	186.5	189.7	192.9
7.0	196.0	199.2	202.4	205.6	208 7	211.9	215.1	218.5	221.8	225.2

(7) *Permanganate Test.*— The solution is approximately $\frac{N}{100}$. The test is carried out in a Nessler tube, using 50 c.c. of the water and adding the solution drop-wise, noting the amount required and the rapidity with which the pink color vanishes. The test carried out in this way can, of course, be considered advisory only.

(8) *Iron.*— This test will be most useful in the case of well waters, to which it may be applied directly without evaporating.

Take 50 c.c. of the water in a Nessler tube, make it distinctly acid with hydrochloric acid and add the $\frac{N}{100}$ permanganate drop by drop, until a faint permanent pink color is produced. Now add 5 c.c. of the potassium sulphocyanate and mix the contents of the tube. A distinct color will be given with .250 or more parts per 1,000,000 of iron.

(9) *Sulphates.* — The usual qualitative test with hydrochloric acid and barium chloride carried out in a test tube.

Before beginning the analytical work take a comprehensive survey of the surroundings of the water — it may render the analysis easier, or even unnecessary; when a luxuriant growth of green algæ is seen around the outlet of a brook into the pond, a shrewd guess as to the quality of the water may be made without the help of a chemical analysis.

In the case of a well — note the proximity of dwellings and outhouses; look for evidences of drains, cesspools, etc.; note the general character and slope of the soil.

In the case of surface waters — note whether the water seems high or low; whether there is much green growth on or in the water; if a pond, examine if necessary the condition of any brooks or feeders. Much may sometimes be learned by following these for a distance.

Finally, a word of caution may be necessary as to the way in which the outfit is to be used. It must be borne clearly in mind that the apparatus is not gotten up for the benefit of the tyro in water analysis, nor does the fact that the outfit is a simple one imply that the subject of water analysis is thereby simplified; as a matter of fact, more experience in analysis and knowledge in interpretation of results is needed for the use of this apparatus than for regular laboratory work.

It is to be regarded simply as an attempt to apply engineering methods to preliminary or isolated problems in connection with water supplies, a subject which is coming more and more into the province of the engineer. Such an attempt would have been impossible in the past, when the training of the engineer left him entirely ignorant of the technique of water analysis and when the data of the chemist and the biologist was to him an unknown language. This is now changed, and the well-trained sanitary engineer of today has a good working

knowledge of the best chemical, biological and bacteriological methods. It is, then, in the hands of such engineers as these, who have had a sound laboratory training, who know quite well what are the limitations of their apparatus and of themselves, that an outfit of this kind will find its greatest usefulness.

Massachusetts Institute of Technology,
Boston, Mass., October, 1901.

CONTRIBUTIONS FROM THE LABORATORY OF SANITARY CHEMISTRY.

IV.

NOTES ON OSCILLARIA PROLIFICA (Greville).

BY ISABEL F. HYAMS AND ELLEN H. RICHARDS.

FIRST PAPER: LIFE HISTORY.

THIS plant, one of the Cyanophyceæ, was first brought under our notice in the course of our work in connection with the systematic examination of the public water supplies of Massachusetts under the auspices of the State Board of Health. One of these supplies was from Jamaica Pond, which is some eighty rods from the residence of one of us. This body of water lies in a suburb of Boston, about four miles west from Dorchester Bay. It is approximately circular, half a mile in diameter; it is much of the shape of an inverted Mexican hat, with a deep pit somewhat out of the centre, between 50 to 60 feet in the deepest part. One-third of the area is, however, less than 10 feet deep. The shores are sandy and pebbly, with no marshy spots. One cove, probably artificially deepened for a boat landing, runs in between two sharp bluffs and is the only approach to a marshy condition. There is the merest brooklet, feeding the pond for a short time in heavy rains and in wet seasons, most of the water coming from springs. Not since the settlement of the region has there been any outlet. The water is of fair quality, and furnished the earliest public water supply of the City of Boston. The Jamaica Pond Aqueduct Company was incorporated in 1795. Forty-five miles of white pine logs, nearly $1\frac{1}{2}$ feet in diameter, with $5\frac{3}{4}$-inch bore, delivered about 400,000 gallons daily as far as Fort Hill. In 1897 some of these pipes were found in good preservation. A portion of Roxbury was supplied with this water until 1893, when the pond became part of the Park System. Analyses of the water will be found in a later paper.

Some half dozen estates, with two stretches of public road and two ice houses, formed the shore of the pond, and the historian, Francis Parkman, made here his beautiful gardens, to which he brought the treasures of the lands he visited.

In the spring of 1886, the smelts, with which the water is usually well stocked, died in great numbers, and while many were raked from the surface, many more fell to the bottom. The next May there was noticed on the water a light brown scum, which soon disappeared; but during the four years following, the growth was such that the whole mass of water was colored, at times a dirty red, and the scum, washing up on the rocks, decomposed with a rich purple color and a disagreeable odor. The year in which the plant was most abundant, it did not entirely disappear during the winter, but was found embedded in the ice which was cut from the water. In other years it disappeared in July, and the water, which in June was so turbid that nothing could be seen at a depth of 12 inches, became clear to 10 feet or more. It is stated that about 1860 something of the same sort occurred. From 1875 to 1886, however, it was not noticeable. Since its appearance in 1887, the pond has never been free from it; in some years it has been worse than in others, dependent upon temperature and sunlight. No other body of water in America has, so far as we know, been so infested.

During the years 1888 to 1892, many samples, not only of the surface water, but of that at various depths, and of ice cut in winter, came into the laboratory. The results of examinations include microscopical records by a trained botanist; but the exigencies of rapid routine work and the changes in the *personnel* of the staff, for various reasons, together with the fact that the use of the pond as a water supply was to be given up on account of the inclusion of the whole region as a part of the Park System of Boston, resulted in rather fragmentary records. The observers by no means agreed among themselves as to the name of this plant, and its life history appeared to be quite unknown.

Our interest was aroused by the mystery surrounding this alga, so peculiar to this pond, so constant in its occurrence, and abundant in quantity as to almost exclude other forms of plant life; and we have made it an object of study during thirteen years.

For the past two years an almost daily record has been kept of the various conditions of its growth and decay, and micro-photographs

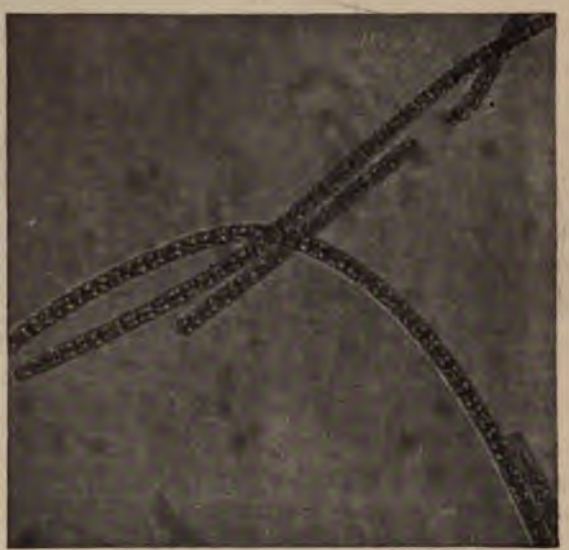

FIG. 1. — OSCILLARIA PROLIFICA. FILAMENTS WITH SHORT COLUMNAR CELLS.

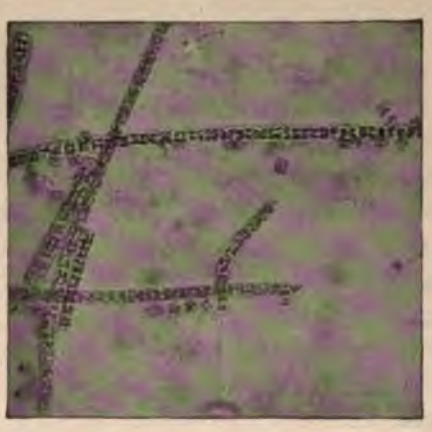

FIG. 2. — SIMILAR TO FIGURE 1. MICROSCOPE FOCUSED TO SHOW THE HIGHLY REFRACTILE BODIES IN THE CELLS.

have been made of the more important phases; so that many points have been determined in its life history, in its chemical composition, and in its relation to the general question of water supply.

We allow the accompanying illustrations (Figures 1, 2, and 3) to serve for the technical botanical description and confine ourselves to the behavior of the plant.

Doubtless the difficulty experienced by earlier observers in identification was due to the great changes in size, color and appearance at different times and to the rarity of spore formation. Constant observation, however, shows the continuity of all phases and renders absolutely certain the identity of the differing forms.

Oscillaria prolifica well deserves its name, since its increase under favoring conditions is marvelous. On a given day no one but a close

FIG. 3. — OSCILLARIA PROLIFICA. FILAMENTS OF ELONGATED BARREL-SHAPED CELLS, SHOWING TWO CELLS IN PROCESS OF DEGENERATION, AND ONE THAT IS PROBABLY BECOMING A SPORE.

observer would see in the turbidity of the water any indication of the possibilities which within twenty-four hours may give a floating mass of many hogsheads in volume and covering acres in extent. For instance, in 1898 the first "scum" was collected on May 26. On June 11 the water barely appeared turbid in a depth of 1 foot, and only on the margin of the east shore was the fresh growth plainly visible, at 6 P.M. The next day, Sunday, was bright and very warm. Monday morning, at 6 A.M., the water was opaque, and large patches, like red brown cream on a pan of milk, floated in the gentle breeze. The patches were of several square yards in extent, and as the wind freshened they piled up, like Nansen's ice, until the skimmer took up thick clots like rich cream. Several gallons of this cream, nearly pure Oscillaria, was obtained.

The strong wind soon broke up the mass, and cold, cloudy weather followed, so that no more scum was seen; and on June 24 the water

FIG. 4. — FILAMENTS IN THE BROKEN CONDITION.

FIG. 5. — FLOATING MASSES OF OSCILLARIA ON JAMAICA POND, JUNE 12, 1901.

was clear to the depth of 4 to 6 feet, and the only source of specimens was the impure sediment obtained by washing the stones and gravel on which it had settled. At this date the color was green, no longer red brown. A mass of it was dark olive-green, and that which had settled on the stones was broken in short pieces, with peculiar cells on the ends, as if these cells formed a line of weakness. (See Figures 3 and 4.) In the earlier stages of growth the ends of the fila-

FIG. 6. — GATHERING THE SCUM ON JAMAICA POND, JUNE 12, 1901.

ments are blunt pointed like the head of a tape needle. (Figure 1.)

During the time of abundant growth no spores are found, only the long, interlacing threads, forming a thick felt. Figures 5 and 6 show the masses of Oscillaria being driven before the gentle breeze, at 8 o'clock, on June 12, 1901, small patches being visible at least halfway across the pond. On the day before, the "cream" was collected from the opposite shore, the wind having been from the south. Nearly a barrel of the drained substance was collected in

these two days, and one hundred barrels might easily have been obtained. In a week the plant had disappeared from the surface, and the water was clear to a depth of 2 or 3 feet. In each of these thirteen years there have been two days only on which collection could be made of any quantity; on three to five days a slight scum was found. The following table of the years 1900 — 1901 will serve to show the regularity of growth, confirmed by many other observations.

Date. 1900	Temperature of water.	Appearance.	Date. 1901.	Temperature of water.	Temperature of air.
		First sample observed.	April 2	43° F.	43°
April 9	48°	"	April 10	43°	41°
April 24	51°	"	April 24	43°	41°
April 29	53°	"	April 29	49°	60°
		First film seen. Between April 2 and April 24 only three days of sunshine. Film green, not brown.			
May 8	52°		May 8	57°	64°
May 10	51°	Slight scum	May 9	55°	
			May 14	62°	
			May 22	64°	80°
		Slight film	May 26	55°	
		Green scum with brown streaks	June 3	58°	
			June 5 (surface)	73°	
		Abundant growth	June 11 (deeper)	61° 64°	52°
		Abundant growth	June 12	67°	
June 15	70°		June 19	69°	
September 20		Spores. Frothy.	September 22		

Not until the end of August do even occasional spores show themselves. (Figures 7 and 8.) By the middle of September they are not uncommon, but they are never abundant even in October. They

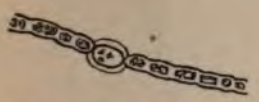

FIG. 7. — PORTION OF FILAMENT OF OSCILLARIA PROLIFICA BEARING A SPORE. Cells barrel-shaped, color bright green. The Spore is lighter in color and more homogeneous in structure than the other cells and is surrounded by a thick, colorless envelope. From living material collected Oct. 19, 1901, and treated on the slide with formaline and iodine. Camera lucida drawing by R. P. Bigelow. ×705.

apparently serve to carry the species through exceptionally severe conditions. For the most part, the plant breaks up into short pieces of two or four divisions, as shown in Figure 4, and thus propagates by segmentation. These fragments become decidedly heavy and rest on the bottom, especially on the stones, at a depth of 2 to 4 feet around the edge of the water. They appear to be suspended in the denser water near the bottom of the shallower portion. They are not abundant in the mud of the bottom at the greatest depth. From which we may say, in general, that *Oscillaria prolifica* lies dormant, either in the form of broken threads of various lengths and various stages of arrested development, or in the form of spores during the winter. That, as spring advances and the surface of the water becomes warmed to a temperature of about 60° F., the plant begins to grow, and continues, so long as food and other conditions last, until the water reaches a temperature of 72°, when rapid breaking up occurs. A week of cool weather in midsummer, as in 1891, will often allow of an increased growth, and a succession of warm days in late October will frequently permit of a fairly vigorous growth along the edges where the water is warm.

Certain chemical considerations will be given in another paper as to the food of the plant.

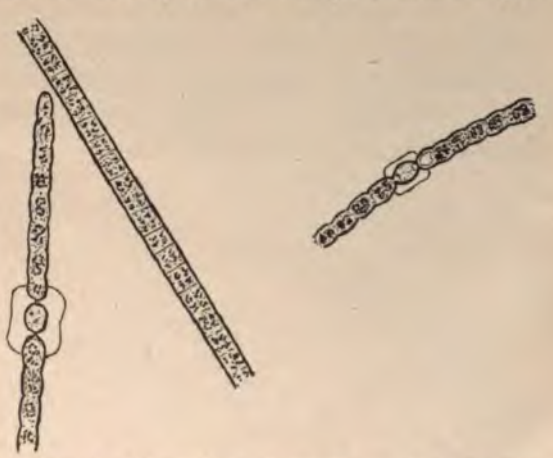

FIG. 8. — OSCILLARIA PROLIFICA. Two filaments bearing Spores as in Figure 7, and part of one filament with short columnar cells, color olive-green. Spores were not observed in filaments in the latter condition. Material same as Figure 7. Camera lucida drawing by R. P. Bigelow. ×765.

The most remarkable variation in color occurs under the varying conditions. At the time of the first observations, 1886 to 1890, the color in early spring and late fall was an ocher yellow to a Bismarck brown. The same shade is observed when an October growth appears. In June, during the period of greatest growth and longest days of sunshine, the whole mass of water, when stirred by the wind, appears a brownish red, sometimes suggesting chocolate, sometimes more like dried blood. On still mornings, after a hot, sunny day, the large patches found floating on the surface, many square yards in extent, are of an orange brown color. These are composed of the new growth of the day before, and soon become distributed into the deeper layers by the wind, or are driven on shore to decay on the rocks, giving to them a rich purple coating, while the surface of the water is covered with a froth, especially around the edges. In July and August, during all these thirteen years, the color has been uniformly green, usually a more or less brilliant blue-green, justifying the right of this species to be classed with the Cyanophyceæ. The pond in some seasons is of a very rich color; in others, as in 1901, a light, dirty green. In the resting stage the color is always blue-green. In short, whenever the plant is found below the surface, it is blue-green in color.

The odor of the growth is a strong grassy odor, not unpleasant; but the odor of decay is intensely disagreeable, fetid rather than putrefactive. In years when the plant is abundant, the odor is evident along the shores of the pond; but, as a rule, it is not distinguishable to any but the experienced nose.

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